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IMPERIAL INSTITUTE OF ENTOMOLOGY.

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Vol. **35.** 1944.

THE STABILITY OF ROTENONE IN A PHENOL-OIL SOLUTION.

By G. G. Robinson,

London School of Hygiene and Tropical Medicine.

It is known that, in solutions of some organic solvents such as pyridine, chloroform, ethylene dichloride and acetone, rotenone changes by oxidation to various derivatives, giving the solution a characteristic yellow colour (Jones & Haller, 1931). There is an accompanying loss in toxicity. Now that various intermediate solvents for rotenone in oils are being studied, it becomes of interest to know the stability of rotenone in these solutions.

In a recent paper (Robinson, 1942), it was reported that xylenol, obtained from coal-tar distillation, was a suitable substance for bringing rotenone in solution with petroleum oil with an admixture of vegetable oil. Tests had shown that no deterioration took place within six weeks. A solution has now been retested after one year's storage in ordinary reagent bottles kept in the dark but with ample access to the air. The test animal was the tick, *Ornithodorus moubata* (Argasidae), third-stage nymphs of which were subjected to the spray under similar conditions to those used in previous work (Robinson, 1942).

The spray solution consisted of 60 per cent. medium Shell oil P31, 15 per cent. ground-nut oil and 25 per cent. xylenol and contained 1·5 per cent. pure rotenone. The xylenol may be defined as low temperature tar-phenols distilling between 210–220°C./760 mm. The Shell oil had specific gravity 0·857 (15°C.), initial boiling point 300°C., viscosity (Redwood I) 141 seconds (20°C.), and unsulphonatable residue 99·2 per cent.

The year-old solution was compared with a similar solution made freshly. The results are seen in Table 1.

TABLE I.

The toxicity of a phenol-oil solution of rotenone (1·5 *per cent. wt/vol.*) *made freshly compared with a similar solution one year old. Tested against third stage nymphs of* Ornithodorus moubata.

No. of ticks per dose	Dose mg/cm²	Percentage Mortality	
		Fresh solution	One year solution
20	0·051	40	
	0·061		80
	0·077	80	
	0·087		90
	0·103	90	90
	0·128	95	100
	0·154	100	100

The data were analysed statistically by the probit method of Bliss (1935, *a* and *b*) and the regression equations are shown in Table II.

TABLE II.

Regression equations based on data in Table I.

Solution	Regression equation	n	χ^2	P
Fresh	$y=5{\cdot}0686x-1{\cdot}2142$	2	0·3899	$0{\cdot}8>P>0{\cdot}7$
One year old	$y=3{\cdot}4044x+3{\cdot}1129$	1	0·6400	$0{\cdot}7>P>0{\cdot}6$

The variables in the equations, x and y, are the logarithm of the dose and the mortality probit respectively. For ease of calculation 2 was added to the logarithms of the doses. n is the number of degrees of freedom of the regression lines, χ^2 is a measure of how far the experimental points diverge from the expected log-probit line and P is a measure of the probability that these divergences have occurred purely by chance. A comparison of the slope and position of the regression lines gave the following values :—

For slope ... ... $t=1{\cdot}33$, $0{\cdot}3>P>0{\cdot}2$

For position ... $t=1{\cdot}65$, $0{\cdot}2>P>0{\cdot}1$, where n, the number of degrees of freedom, was 3, t indicates the magnitude of the difference in position or slope of the lines and P is a measure of the probability that this difference or similarity has occurred by chance.

This experiment shows that the year-old solution of rotenone was fully as toxic as a fresh solution. Two repetitions of this experiment were done, and the results were substantially the same.

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ANOPHELES HISPANIOLA, THEOBALD, 1903 (DIPT., CULICID.) FROM THE EMIRATE OF TRANSJORDAN.

By Major W. H. R. Lumsden, R.A.M.C.

General.

During a general survey of malaria in Transjordan, which was carried out in the summer and autumn of 1942, the Anopheline here discussed was found to be widely distributed and often common. It was first seen as an adult female, then considered to be *Anopheles* (*Myzomyia*) *turkhudi*, Liston, 1901, brought from Amman, Transjordan, in May 1942 by Capt. H. F. West, R.A.M.C. It is of value to describe the present material and compare it with such descriptions of the other members of the *turkhudi* group as are available to me at the moment, though it is considered that in no respect does it differ widely enough from *A.* (*M.*) *hispaniola*, Theobald, 1903, to be accorded more than varietal rank within that species.

I wish to record my appreciation of the help given me by Professor Saul Adler who made available to me the laboratory facilities and literature of the Hebrew University in Jerusalem. I am indebted also to Lieut.-Colonel J. E. Measham, R.A.M.C., for permitting me to submit this description for publication.

The main material consists of eggs, larvae, pupae and adults derived from females collected in the Arab Legion Stables at Amman, Transjordan, on 17th June, 1942.

Numbers in parentheses indicate the number of measurements or examinations of each character on which the description is based.

Egg.

The egg closely resembles that of *A.* (*M.*) *turkhudi* as given by Edwards (1926). No floats are present, and the frill is reduced to a tiny oval rosette, about one-sixth of the egg-length in longer diameter, on the upper surface of the egg at the broader end. The exochorion is very finely bossed. Most eggs sink within a few hours of being laid.

The dimensions are :—Length : mean 584μ ($\sigma=23{\cdot}6\mu$) (12) ; Maximum breadth: mean 150μ (6) ; Maximum depth : mean 153μ (6). Material preserved in formalin is slightly smaller, the mean length being 522μ (10).

Fourth-stage Larva.

The full-grown larva is 6–7 mm. long, muddy-yellow in colour, with a black head and a fairly well-developed dark spot dorsally on abdominal segment IV.

The following description is based on the examination of 9 larvae, 3 bred from each of the 3 females which laid fertile eggs.

Head.—The entire dorsal surface of the head may be dark with the exception of the margins of the fronto-clypeus and the antero-lateral parts of the epicranial plates. Paler specimens show dark markings arranged as follows : a large dark spot enclosing the bases of the inner frontal hairs ; a transverse row of 3 spots behind the frontal hairs ; a U-shaped spot, concave forwards, behind these ; the posterior third of the epicranial plates, extending further forwards along the suture. The antenna is more darkly pigmented towards its apex. It carries short conical spines in about its middle half but only on the medial and ventral surfaces (12).

Table I shows the condition of the more important hairs. In this and following tables, simple hairs are shown as one branched.

TABLE I.

Hair No.	Name	Branches	No. examined
2	Inner clypeal	1	12
3	Outer clypeal	1	12
4	Post-clypeal	1	12
5	Inner frontal	6–13	12
6	Mid frontal	6–9	11
7	Outer frontal	6–11	11
8	Sutural	1–2	14
9	Trans-sutural	3–6	8
10	Terminal antennal	1–4	18
11	Antennal	1	12
12	Basal	Pinnate	12

The inner clypeal hairs are quite simple and are separated by 1·4–2·9 times the mean inner-outer clypeal distance (6 larvae measured). Hairs 2, 3 and 4 are of proportionate length 100 : 50–57 : 81–96·5 respectively (6 larvae measured). Hair 9 is missing in the three larvae examined from one of the females. Hair 10 branches near its tip except in one case in which it is divided from its middle. Hair 11 is long, about $\frac{3}{4}$ the diameter of the antennal shaft at its origin ; it is placed at 38–56 per cent. of the shaft length from the base (12).

Thorax.—Tables II–IV show the condition of the most important hairs on the pro- meso- and metathorax respectively.

TABLE II.

Prothoracic hairs.

Hair No.	Name	Branches	No. examined
1	Inner submedian prothoracic	14–22	12
2	Middle submedian prothoracic	11–18	11
3	Outer submedian prothoracic	1	12
9	Anterior dorsal pleural	12–19	6
10	Anterior ventral pleural	1	6
11	Posterior dorsal pleural	11–17	6
12	Posterior ventral pleural	1	6

The bases of hairs 1 and 2 are strongly chitinised and separate. Hair 3 is about half the length of hair 2 ; its base is usually supported by a thin chitinous expansion of the base of hair 2. Hairs 9 and 11 are pinnate.

TABLE III.

Mesothoracic hairs.

Hair No.	Name	Branches	No. examined
9	Anterior dorsal pleural	10–15	6
10	Anterior ventral pleural	5–8	6
11	Posterior dorsal pleural	1	6
12	Posterior ventral pleural	2–3	6

Hairs 9 and 10 are pinnate. Hair 11 is 1/6–1/10 of the length of hair 12.

TABLE IV.

Metathoracic hairs.

Hair No.	Name	Branches	No. examined
1	—	3–5	12
2	—	3–5	12
3	—	1–3	12
4	—	1–2	12
9	Anterior dorsal pleural	About 30–45	6
10	Anterior ventral pleural	10–21	6
11	Posterior dorsal pleural	Minute papilla	6
12	Posterior ventral pleural	4–6	5

Hair 1 is branched only. Hair 2 is about ½ the length of hair 1. The branches of hair 3 are fine and in the distal one-third of the hair. Hair 4 is about twice the length of hair 3.

Abdomen.—The anterior tergal plates do not overlap the full gut. Posterior tergal plates are present on segments II–VII and are small and round. No accessory sub-median plates are present. Table V shows the condition of hair 1 on each abdominal segment.

TABLE V.

Hair No. 1, *abdominal segments* I–VII.

Segment	Condition	Branches or leaflets	No. examined
I	Branched	2–3	12
II	Semi-palmate	2–11	12
III	Palmate	9–15	11
IV	Palmate	12–18	12
V	Palmate	13–21	12
VI	Palmate	9–16	12
VII	Palmate	8–13	12

The blade of the leaflet is about six times as long as its greatest breadth. The filament is about one-sixth the length of the blade. Its beginning is marked by one to four or more notches which are usually right-angled, resembling a succession of steps. The filament is stumpy, sometimes sharp-pointed, sometimes slightly truncated.

Table VI shows the condition of hair 6 on abdominal segments III–VI.

TABLE VI.

Hair No. 6, *abdominal segments* III–VI.

Segment	Condition	Branches	No. examined
III	Pinnate	28–37	12
IV	Branched	6–10	11
V	Branched	5–8	12
VI	Branched	3–7	12

The pecten has 4–5 large, and 7–10 small, teeth (6). The saddle hair is simple and about 1·5 times as long as the saddle. Only the outer submedian caudal hairs and the middle hairs of the ventral brush are hooked (3). The anal papillae are finger-like and about 0·6 of the saddle length.

Larvae taken in the field agree closely with the foregoing description except that the head marking is usually less extensive. In the palest examples seen, however, dark spots remain around the bases of the inner and mid-frontal hairs as in *A.* (*M.*) *multicolor*, Cambouliu, 1902.

Pupa.

The main dorsal setae on segments III–VIII are as follows (5 pupae examined) :—

Seta A.—On segment III, simple, short and blunt, about ¼ the segment length ; on segments IV–VII, simple, sharp pointed, slightly curved, and about ⅓, ½, ⅔, and ⅔, respectively, of the segment length ; on segment VIII with 9–13 branches. *Seta B.*—On segment III, 3–5 branched ; IV, 2–5 branched ; V, 3–5 branched ; VI, 2–4 branched ; VII, 2–4 branched. *Seta C.*—On segment III, 2–4 branched ; simple, about 1·5 times the segment length, on segments IV–VII (occasionally bifurcated). *Paddle.*—Lateral border with spines on its posterior ¾, those of the posterior half larger and about 15–30 in number ; 11–17 fine hairs on the posterior border between the last spines and the origin of the paddle hair ; paddle hair about ⅓ paddle length, strongly hooked ; accessory paddle hair about ⅓ length of paddle hair, 3–4 branched.

Adult Male.

The description is compiled mainly from the examination of 6 males, two from each of the 3 females which laid fertile eggs. *Head.* Vertex and occiput dark brown with narrow whitish bands on the eye margins ; sparsely clothed with erect forked scales, black laterally, white in the middle, forming a white median line with a few scattered white scales on each side of it. Frontal tuft is well developed, of creamy-white scales, reaching as far as the tori. *Antenna.* Tori dark brown ; flagellar joints yellow, darker at the origins of the whorls, except the last two segments which are all brown ; flagellar hairs, pale golden, shining. Proboscis dark brown, slender, with the scales appressed ; labella yellowish. Palp with the club slender and bearing usually 2 broad white bands, one basally and one about the middle. The latter may be reduced to a dorsal white spot or be absent altogether. The tip of the club is broadly white. *Thorax.* Mesoscutum brownish or greyish ; middle area covered with narrow (6–7 striations), recumbent, creamy-white scales ; no scales on the sloping lateral parts except for an ill-defined line of hair-like scales above the wing base. *Legs.* Black-scaled, with well-marked pale spots at the femoral and tibial apices and faint pale bands at the apices of the tarsal segments 1–4. *Wing.* C carries five dark markings, the first basal and sometimes with a short white interruption. The total length of black, and of white, scaling are nearly equal. Sc has 2 dark markings underlying the 2nd and 3rd on C. R and R1 together have 4 dark markings corresponding with the 2nd to 5th costal spots but the first and second are not so extensive as those on C, underlying only the distal half or two-thirds of these spots. The veins behind R1 are very variable but a typical arrangement of short black marks is as follows :—on RS below the second spot of R1 ; on the petiole of the anterior fork cell and on its fork ; on R2 and on R3 ; at the base and tip of R4+5 ; at the tips of the branches of M ; near the base of Cu, and on its upper fork, immediately distal to the medio-cubital cross vein and at its tip ; in the middle of A. *Wing-length* : 3·5–3·9 mm. (5). *Abdomen.* Ground colour brownish or greyish with pale hairs and no scales. *Hypopygium.* Parabasal spines four to seven in number (10 groups examined), all thick and bent inwards at their tips ; one of the outermost distinctly longer than the others. There is a further slender hair distal to this group but it is little differentiated from the clothing hairs. Harpago with a club and a variable number of hairs. In 10 examined, five had 2, four had 1 and one had no hairs. A distinct large apical hair was present in five only. Mesosome with 5–8 leaflets, the longest about half the length of the mesosome.

Adult Female.

The description is compiled mainly from the examination of 5 females bred from the 3 females which laid fertile eggs. They differ from males as follows :—

Head. Vertex and occiput more densely scaled, the central white patch better marked in width about one-third the diameter of the head. *Antenna.* Torus and flagellar joints dark brown. Palps slender, dark brown with three white bands, the scales appressed, except for a few dark scales on the first and second segments which are erect. The white bands are at the junctions of segments 2 and 3, 3 and 4, and 4 and 5, the proximal band longest, the distal shortest. The palp beyond the distal white band is entirely dark in 17 out of 40 females examined for this particular character. The remainder show a varying amount of white scaling at the extreme tip. When this is well developed the end of the palp resembles the sub-divided white tip which is sometimes seen in *A.* (*M.*) *superpictus*, Grassi, 1899. When entirely dark the tip is about three times as long as broad. The last palpal segment is 6·5 times as long as its greatest breadth (1). The palps are 1·5–2·3 (mean 1·8) times the thoracic length (12). *Thorax.* The scaling of the mesoscutum is distributed as in the male but is more dense. *Wing.* C, Sc, R and R1 are as in the male but R1 sometimes has an additional small black spot under the proximal end of the last spot of Sc. The dark markings on veins behind R1 are variable but more extensive than in the male. The arrangement is little different. In addition M is dark from the level of the second costal spot as far as the medio-cubital cross vein. A carries 3 dark spots, or only 2, the proximal being undeveloped. *Wing-length* : 4·0–4·3 mm. (5). *Buccopharyngeal armature.* The foundation of the teeth is strongly curved. Rods and cones alternate, the latter having deep-set bases. Cones number 16 to 24 (5).

Systematic Position.

Three previously described species of the subgenus *Myzomyia* form a well-defined group. They are *A.* (*M.*) *turkhudi*, List., *A.* (*M.*) *hispaniola*, Theo., and *A.* (*M.*) *italicus*, Raffaele, 1928. The buccopharyngeal armature of *A. italicus* is undescribed, but otherwise the main characters of taxonomic importance are known.

The position of these species in various systems of classification is as follows :—Hypopygial characters—Group III B of Christophers (1915). Buccopharyngeal characters—Class E of Barraud and Covell (1928). Larval characters—Division B, Sub-division IV, Group 6 of Puri (1931). The group is most clearly defined on larval characters, Puri's Group 6 including only these three species. The species now described fall into the same grouping on these characters. *A.* (*M.*) *flaviceps*, Edwards (1922) should perhaps also be placed here, but is insufficiently known and will not be discussed. *A. turkhudi* is quite distinct from *A. hispaniola* and *A. italicus* on larval characters. The descriptions of the latter two species available to me are Christophers (1929), Martini (1931) and Senevet (1935) for *A. hispaniola* and Raffaele (1928) for *A. italicus*. There are only minor differences between the two species from these descriptions, and it seems likely that comparison of material will show them to be only varieties of one species. This conclusion is supported by the failure of Senevet (1934) to find pupal differences and by Sergent's (1937) redescription of the egg of *A. hispaniola*, which showed it to be of the same type as that of *A. italicus*. The eggs of all three species are floatless, and the frill is reduced or absent. The species now described cannot be separated definitely from *A. hispaniola* or *A. italicus*, at least on the descriptions at present available to me. It has been compared with one male and two female specimens, labelled *A. italicus*, in the Hebrew University. These agree very closely with the present material on characters of external morphology. The females both show a short white tip to the palps which is also frequently seen in the present material. This is not mentioned in the descriptions of *A. italicus* or *A. hispaniola* at present available. As regards the larvae, Senevet (1935) states that hair No. 1 of abdominal segment I is semi-palmate, while it is only branched in the Transjordan specimens. The palmate hair leaflet of abdominal segment V is shown by the same author with a narrower filament than is found in the present material. On both these points, however, the Transjordan material agrees with Christophers' (1929) description. The Transjordan material is, on the whole, considered to be insufficiently different from *A. hispaniola* as described by these several authors to merit specific rank.

Distribution, Breeding Places and Occurrence of Adults.

The species is generally distributed in South-Western Transjordan in the wadis which drain into the Jordan-Wadi Araba rift valley. It has not been taken in Palestine, nor in Transjordan north of the basin of the Nahr Zerka. Its range extends to the borders of Saudi Arabia in the South. It ranges in altitude from 400–1,175 metres. Locality records for this species are as follows :—Majdal, Sukhne, Salt, Safut, Yajuz, Nahr Zerka, Wadi Sha'eb, 'Ein id Deir, Amman, Reseife, Na'ur, Wadi El Hasa, Petra, Wadi Musa, Tafileh, Ma'an, Wadi Ram. Thirty-three collections were made of larvae. Its main breeding places were in algal mats in wadis and in foot-holes among seepage, but it was occasionally found among stones and in small pools at the heads of springs. It was associated 26 times with *A. superpictus*, 9 times with *A. sergenti*, 3 times with *A. claviger* and once each with *A. dthali* and *A. turkhudi*. It occurred alone in 4 collections. Larvae were found between 31.v and 28.x.1942. Adults have not been found in houses but have been taken in stables along with *A. superpictus* (Amman, 17.vi.1942 and 18.vii.1942 ; El Sukhne, 17.vii.1942). Biologically also, therefore, the species conforms to *A. hispaniola* as described from the Western Mediterranean area. Most of the localities from which the species is recorded are malarious but *A. superpictus* also occurs. The importance of *A. hispaniola* in this respect has yet to be investigated in Transjordan.

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THE USE OF CARBON DIOXIDE PRODUCTION AS A MEASURE OF INFESTATION OF GRAIN BY INSECTS.

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Introduction.

Four methods are available for the estimation of the insect population infesting a sample of grain. These are :—

(*a*) Sieving to remove free living insects, which may then be counted or weighed.

(*b*) Direct examination of the sample spread thinly on a tray.

(*c*) Dissection of a number of grains from the sample.

(*d*) "Breeding out," *i.e.*, storing the sample under favourable conditions and examining it periodically for insects which may have developed.

Sieving is a standard normal method for all free living insects that are appreciably smaller than the grain. It is not applicable to the larger larvae, particularly Lepidopterous larvae, for which direct examination of a sample spread in a thin layer on a tray is the only appropriate method. Also, it is not applicable to larvae which develop within the grains. These include the species of *Calandra* which are among the commonest and most destructive of grain pests. Further, neither sieving nor direct examination will detect all the smaller pests (*e.g.*, mites), particularly if the sample contains grains holed by previous weevil attack.

Dissection of grains is an exceedingly laborious method of estimating infestation, but at present it is the only one that can be used to give a result within a few hours for *Calandra* larvae. It is a method which can only be used by an expert with considerable experience, but it does give information concerning the proportion of eggs, pupae, and various stages of larvae which may be present.

Complete breeding out takes at least six weeks for *Calandra* under optimum conditions and longer for most other insects. During this period, emerging adult insects must be removed by sieving and be counted or weighed, at least once a week. Thus, all these methods have serious disadvantages, and since a method to give at least an approximate measure of infestation in a short time is urgently required, special attention was paid to this problem.

The pests of grain are normally active and have a metabolic rate enormously greater than that of the grain in which they live. It was therefore thought that the rate of carbon dioxide production of infested grain, as a measure of metabolism, would probably be a satisfactory measure of the infestation. Further, experiments at this laboratory have shown that the volume of air in bulks of all varieties of wheat is nearly constant, varying between about 38·5 per cent. and 39·5 per cent. (Page & Lubatti, 1937, Jones, 1943). Hence it is possible to measure the rate of carbon-dioxide production, in a container of any size which is completely filled with grain, as the *concentration* developed in the inter-granular air in a given time. This simplifies the measurement considerably since it avoids the necessity for weighing the sample or of standardising the volume of container used.

The carbon dioxide method gives considerably less detailed information than a combination of the more laborious methods enumerated above, since it does not distinguish between the infesting species and it gives no indication of the age distribution or likely multiplication rate of the population. Nevertheless, it has one great advantage over these methods : it gives an estimate of the actual amount of damage which the infesting population is causing, on a basis of metabolic rate, and this provides a common basis for the comparison of different species. The rate of metabolism must be related, though possibly not very closely, to the amount of grain consumed by the insects and is directly related to the amount of heat which they are producing. Since insects are responsible for a large proportion of the " spontaneous " heating which occurs in stored grain, this is an important feature.

With certain precautions, the method has proved useful in population studies now in progress in the laboratory, but its chief application probably lies in routine observation of grain in storage, and for this purpose no special care is necessary.

Brief Description of the Method.

(*a*) Grain to be tested is placed in an airtight container which it must completely fill.

(*b*) The grain is then incubated at a standard temperature for a standard time.

(*c*) The concentration of carbon dioxide in the interstitial air is estimated. This concentration (the " carbon dioxide figure ") gives an estimate of the infesting population.

Apparatus required.

(*a*) *Airtight containers for grain.*—The containers may be of any size that can be conveniently filled. Glass bottles of 500 cc. (16 fl. oz.) capacity have been found to be suitable. The bottles are best closed with rubber stoppers ; screw-topped bottles are unsatisfactory as it is difficult to make them air-tight and grains are apt to get under the washers. A tube of small bore (about 1–2 mm.) for withdrawing the air sample must be provided. The tube must be closed during the incubation and should be fitted with a glass stop-cock, although a short length of rubber tube with a clip may be used.

(*b*) *Incubator.*—Temperature control should be within the range ±1°C. (1·8°F.) at 25°C. (77°F.).

(*c*) *Syringes.*—A syringe should be used for withdrawing a portion of the interstitial air for analysis. It must be completely airtight and should hold sufficient air for two analyses by whatever apparatus is available. All-glass syringes of 20 cc.(two-thirds fl. oz.) capacity have been found convenient using either a 10 cc. Haldane apparatus or the 5 cc. apparatus described by Oxley (1944). Syringes should be lubricated with heavy medicinal paraffin oil.

(*d*) *Gas Analysis Apparatus.*—A gasometric method is appropriate as it is required to measure a concentration of carbon dioxide and not an absolute quantity, and the accuracy of such methods is of the required order (about ± 0·2 per cent. CO_2). A catharometer is ideal if large numbers of samples have to be dealt with, but is likely to be too elaborate and expensive if only small numbers of samples are examined daily. One of the authors has described a very simple gasometric method which has been designed specially for the method and has been found satisfactory and reasonably portable (Oxley 1944).

Procedure.

(*a*) *Sieving.*—A sample may be sieved when received in order to remove all free living insects except large larvae. These may then be counted while a carbon dioxide determination is made on the sieved sample. The accuracy of interpretation of the results is thus increased since the carbon dioxide method is used only to measure the insect population not removed by sieving. Sieving and counting, however, are tedious processes and, if an estimate of total life is all that is required, as will normally be the case, sieving may be omitted and all insects in the sample may then be included in the incubation bottle.

(*b*) *Pre-incubation.* -Interpretation is made more reliable if, before grain samples are sealed up for incubation, they are kept for any convenient period up to 24 hours at 25°C. in order to acclimatise the insects to the unusually high temperature. This is more important when the grain bulk is cold. During the pre-incubation period the samples must not be sealed up. They should be submitted to this treatment in small bags, wide-mouthed jars with open tops, trays, or open tins, covered with muslin to prevent the escape of free living insects.

(*c*) *Airing.*—At the beginning of incubation it is important to ensure that no carbon dioxide is sealed up with the grain sample. There may be carbon dioxide in the air within or between the grains, or in the air in the bottle. If the grain sample has been kept in a bag it is probably already sufficiently aired, but if it has been in a tin or airtight bottle (this is undesirable since it may affect the vitality of the insects), an airing is essential. This is also necessary if the sample has been withdrawn only a few minutes previously from the main bulk of grain, since the atmosphere in the bulk may well contain an appreciable concentration of carbon dioxide, some of which will be retained within the grains. Each sample should therefore be aired as a matter of routine by being spread thinly on a tray or sheet of paper for about 15 to 30 minutes before bottling up. Bottles that have not been open to the air during the previous few hours should be aired by blowing air into them or evacuating them and refilling with room air.

(*d*) *Water content.*—Wherever possible, it is advisable to determine the water content of the grain since the carbon dioxide output of clean grain varies with water content (see p. 14). If this is to be done, the sample for water determination should be taken immediately before bottling for incubation. Water content is unimportant below about 15 per cent., and if it is certain that the grain does not exceed this dampness, a determination need not be made. At this stage also, it is well to note whether the grain is visibly mouldy, as such grain cannot effectively be tested for insect infestation by the carbon dioxide method.

(*e*) *Filling the bottles.*—Bottles must be dry before they are filled. To ensure constancy of packing, and hence of intergranular air space, fill the bottle, shake down by tapping a few times on the table, and make up the level with a few more grains. The stopper may then be put in place and pushed well down until it is firmly in contact with the grain in the bottle. Close the capillary tube by the stop-cock or clip.

(*f*) *Incubation.*—The normal conditions for incubation are 24 hours at 25°C. If other periods are used the interpretation must be modified accordingly, as explained below (p. 14).

If large bottles are used, time should be allowed for heat to penetrate the mass of grain. From measurements which we have made, the following empirical rule has been developed which gives with sufficient accuracy the extra time which is necessary for warming up, when grain originally at a temperature between 10°C. and 15°C. is incubated at 25°C.

$$t=4{\cdot}2\left(\frac{d^2}{4}-12\right)$$

where t=extra incubation time in minutes.

d=external diameter of the bottle (cylindrical) in centimetres.

The correction may be neglected if the extra time which is found to be necessary is less than half an hour as it is for all ordinary bottles up to 500 cc. capacity, and larger tall narrow bottles.

(*g*) *Removal of air for analysis.*—Expel all air from the syringe, connect it by a short rubber tube to the bottle, open the stop-cock or clip, and draw air into the syringe. In order to mix the small amount of room air which is present in the rubber tube with the air in the bottle so that it introduces a negligible error, the piston of the syringe should be moved back and forward several times and finally the stop-cock closed while the piston is held out to its full extent. When the piston is released it will move inwards until the air in the syringe is at atmospheric pressure. Close the rubber tube with a clip before disconnecting the syringe from the bottle.

(*h*) *Analysis of the air sample.*—With a gasometric method, duplicate determinations of carbon dioxide concentration should usually be made in order to get sufficient accuracy but this should not be necessary with a catharometer. The room air in the rubber tube must be well mixed with the gas sample in the analysis apparatus to reduce the error it causes.

Interpretation of Results.

Interpretations are given below on the basis of a 24-hour incubation period at 25°C. If other times are used the carbon dioxide concentration obtained must be converted to this basis by proportion.

Clean grain of less than 15 per cent. water content produces up to 0·25 per cent. CO_2 in 24 hours (much less if the grain is dry and good) so that results up to 0·3 per cent. are considered to indicate clean grain.

A result between 0·3 per cent. and 0·5 per cent. indicates a slight infestation or high water content (over 15 per cent.) and grain giving such a result is probably suitable for storage for not more than a few more months. If such a CO_2 figure is obtained, it may be desirable to incubate the samples for a further 24 hours, without airing, in order to double the concentration and hence reduce the errors of CO_2 estimation.

Grain that gives a result between 0·5 per cent. and 1 per cent. CO_2 should be kept under close observation, and the test repeated at fortnightly intervals. It should be noted that grain which is sufficiently damp or mouldy to produce a carbon dioxide concentration above 0·5 per cent. when uninfested is unsuitable for prolonged storage. This illustrates one advantage of the method, for *a high " CO_2 figure " always indicates a dangerous condition.* In fact a result of 1 per cent. CO_2 or more may be taken to indicate that the grain is highly unsuitable for further storage.

It is possible to estimate from the CO_2 concentration the numbers of certain insects which are present. The precision of the estimate depends upon the information available concerning the sample. Usually this will be limited to an indication of the species of insect present (obtained by sieving the sample as described on p. 12) and the water content of the grain. If only few species are present and the water content of the grain is low, the following data may be used for making such an estimate.

In a sieved sample of grain, 1 per cent. CO_2 indicates an infestation of approximately 0·2 per cent. weevils (*Calandra* spp.), *i.e.* one weevil larva per 500 grains (=approximately 15 g.) or 33 larvae per pound. This estimate is reliable if all ages of larvae are present in approximately equal proportions, which implies that egg laying has proceeded at a constant rate up to the time of sampling. The various larval instars will then be present in numbers proportional to their duration. If there is reason to think that older stages predominate, a lower infestation than this is indicated, while if young stages predominate, the infestation is higher.

In an unsieved sample, numerical interpretation of the carbon dioxide figure is difficult since the proportion of adults to larvae varies very widely. However, it will be seen from the table below that it is possible to use the above figure of 1 per cent. CO_2 per 0·2 per cent. infestation by weevils, for an approximate estimate of the population including adults.

The above figures can be applied when the infestation is predominantly grain weevil (*Calandra* spp.). For other insects the approximate figures given in the table below may be used. In the light of further experience these figures may require some modification, but they are based on the best information at present available. The figures serve to indicate the relative importance of individuals of the pests listed in causing heating in grain.

TABLE I.

Number of individuals per pound of grain which will produce 1% CO_2 *in* 24 *hours at* 25°*C*.

Insect	No. of individuals per lb.	Number of pre-adult stages of weevil to which a larva of species is equivalent
Calandra spp.		
1st stage larvae	160	—
2nd stage larvae	80	—
3rd stage larvae	35	—
4th stage larvae	6–10	—
pupae	30	—
mixture of pre-adult stages ...	33	1
adults	20	—
Rhizopertha adults	60	0·25
Tribolium sp. adults	80	0·25
Ptinus sp. mature larvae	80	0·5
Silvanus sp. adults	200	0·1
Laemophloeus sp. adults	250	0·1
Ephestia sp. mature larvae ...	7	3
Mites (*Tyroglyphus* sp.)	0·15 g.	—
Parasites of *Calandra*	—	1
Tinea granella larvae	—	1

The effect of variations in intergranular air spaces is negligible for all varieties of wheat, peas, split peas, haricot beans, polished rice, and similar small, huskless, hard grains. When the method is to be applied to other commodities, it is necessary to make a correction for the characteristic volume of their air spaces. The correction factors given in Table 2 are calculated from the data of Jones (1943), which may be consulted for information on some other, less common, commodities.

TABLE II.

Correction factors for commodities having intergranular spaces considerably different from those of wheat.

Linseed	multiply CO_2 figure by	0·89
Small yellow maize ...	,, ,, ,, ,,	1·05
White " horse tooth " maize	,, ,, ,, ,,	1·18
Fine oatmeal	,, ,, ,, ,,	1·18
Barley	,, ,, ,, ,,	1·25
Wholemeal flour	,, ,, ,, ,,	1·30
Oats	,, ,, ,, ,,	1·39
White flour	,, ,, ,, ,,	1·41
Wheat germ	,, ,, ,, ,,	1·54
Rolled oats	,, ,, ,, ,,	1·61
Wheatfeed	,, ,, ,, ,,	1·69

Discussion.

The results of the method are subject to the following theoretical sources of variation :—

1. Variation in carbon dioxide output between individual insects of a population.
2. Variations, possibly genetic, between populations of the same species.
3. Variations in carbon dioxide output due to uncontrolled environmental conditions prior to the test.
4. Variations in carbon dioxide output of the grain (including its microflora) in the bulk being tested.

The routine method described has been evolved according to the conditions convenient at this laboratory and is limited by the knowledge available. Thus, although 25°C. is recommended as the incubation temperature, because nearly all our work has been done at that temperature, it is likely that at 28°C. most stored products insects, except possibly *Ptinus* sp., would give a considerably higher carbon dioxide output and the sensitivity of the test would be improved. The metabolism of all the species concerned would not be affected similarly, however, so that Table I would not be valid at 28°C.

A pre-incubation period is suggested because it is not known what effects on insect metabolism are caused by sudden changes of temperature, such as occur when the method is used in winter. Ryan (1941) has shown that if the gastrula of *Rana pipiens* is warmed to a temperature above 18°C. from a temperature below 18°C. its rate of development (and probably its metabolism) is greater than that of controls which have been maintained at the final temperature. The experimental animal gradually becomes adapted to the new conditions. Thus, by analogy with the frog, it seems probable that the effect on insect metabolism of changing temperature will not be perfectly straightforward.

Our statement that 1 per cent. CO_2 indicates a 0·2 per cent. infestation of weevils is based on the data graphed in Fig. 1. Grain containing stages of known age, at a density of one per hundred grains, was tested for carbon dioxide output. The stages tested covered the entire life-history. From these data it was estimated that a mixture of all stages in numbers proportional to their durations, and in total number equal to one per hundred grains, would produce 4·3 per cent. CO_2. Our results for adult weevils are about 10 per cent. lower than those of Lindgren (1935). This may be regarded as quite good agreement.

In interpreting results, it is assumed that carbon dioxide is produced in proportion to the density of population and time of incubation. This is true provided that the carbon dioxide concentration does not exceed about 9 per cent., as about this level carbon dioxide begins to retard metabolism. Where the data graphed in Fig. 1 exceeds this concentration, it was necessary to use populations less dense than 1 per cent. and to obtain the result shown by proportion. There is little information available at present on the effect of concentrations of carbon dioxide lower than 9 per cent., but Saakyan (1938) has shown with *Tribolium confusum*, Duv., that in atmospheres of 1–3 per cent. CO_2, respiration is increased compared with lower concentrations. Above 5 per cent. Saakyan found a sharp decrease in respiration rate.

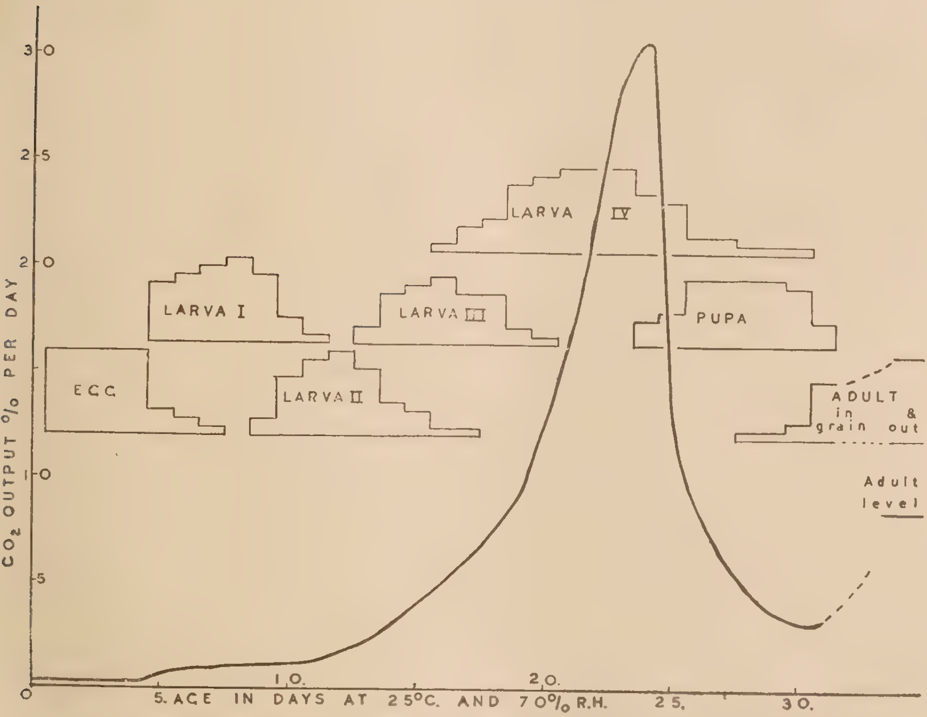

Fig. 1.—Curve showing daily CO_2 output of grain containing one insect per 100 grains. All the weevils are the same age to within a day, since all the eggs in the grains were laid on the same day. The histograms show the number of each stage present per 10 insects for each day after oviposition (obtained from a parallel sample).

The water content of the grain probably has some slight effect on the respiration of insects infesting it. Lindgren (1935) has shown that the respiration of adult *C. granaria* at 25°C. is fairly constant over a range of grain water content from 10–15 per cent. and that of *C. oryzae* rises up to 14 per cent. water content, above which figure it remains fairly constant. The data on which we have based our figures for interpretation of carbon dioxide concentrations were obtained using wheat of water content 13·5 per cent. to 14 per cent. and in subsequent work we have not found any direct effect of water content on insect respiration which exceeds the limits of accuracy of the method.

It has been emphasised that the size of container used for incubation does not affect the method, but we have found it desirable to use bottles not smaller than 250–500 cc. From smaller bottles it is difficult to obtain sufficient air for duplicate analyses and hence errors are likely to be excessive. In addition, it is difficult to obtain a small sample which is representative of a sparse population and the presence or absence of a single insect in such a sample makes a very big difference to the carbon dioxide figure. Very large samples, though desirable, are difficult to draw from grain bulks except from the surface, and surface samples cannot be truly representative. Also, Howe (1943) has shown that surface samples are of less value than deeper ones in examining grain for insect infestations that are likely to cause heating.

Probably the usefulness of this, or any method which is based on the examination of samples, is limited by the precision with which samples can be drawn. Work designed to improve the precision of sampling techniques is in progress at this laboratory, and the carbon dioxide method is a useful tool for attacking this problem.

Practical Utility of the Method.

The utility of the method for examining samples once they have been obtained may be judged from a study of the data which we have accumulated during work in the field over a period of two years. In addition, Dr. C. E. Lucas of University College, Hull, has kindly made available to us data which he has obtained using the method in the course of similar work since November 1942. Both sets of data are included in the following analysis.

We have, for a large number of samples, the CO_2 figure, and hence a " predicted " number of insects, and a record of the number and species actually bred out from the samples. In order to denote the number of insects bred out by a single figure, all species have been converted to numbers of " mixed pre-adult stages of weevils ", using the figures in the last column of Table I which are based on relative carbon dioxide output. No allowance for the age of the insects present has been made, although the breeding out data does give some indication of the stages present. To facilitate the plotting of data, which covers a wide range of population density, the logarithms of both the predicted and the bred out numbers of " weevils " per kilogram have been used. Consequently the samples for which either the predicted or bred out number was zero are omitted and considered separately.

The data are divided into three sets :—(A) large samples approximately 400 g. (500 cc.) or more. (B) Small samples, approximately 65 g., (80 cc.) from Dr. Lucas. (C) Other small samples of approximately 65 g.

Set A contained few insects besides weevils, but some unusual age distributions were found ; set B also were predominantly weevil-infested, but contained in addition some *Rhizopertha* and a few *Laemophloeus* and other insects ; set C were infested by a variety of insects, including parasites and caterpillars.

Taking x=the logarithm of the number of " weevils " predicted,

y=the logarithm of the number of " weevils " bred out,

the regression lines of y on x for these sets of data are : $[(y-\bar{y})=b(x-\bar{x})]$

(A) $y-1{\cdot}171=0{\cdot}912\,(x-1{\cdot}096)$,

(B) $y-1{\cdot}326=0{\cdot}986\,(x-1{\cdot}329)$,

(C) $y-1{\cdot}728=0{\cdot}623\,(x-1{\cdot}769)$.

Table III gives the data from which these equations were calculated and the conclusions that can be drawn from them.

TABLE III.

Data from practical results and estimates of parameters of the regression lines obtained therefrom.

	A	B	C	A+B
S(x)	40·52	154·14	260·59	194·66
S(y)	43·35	153·83	254·02	197·18
S(xy)	58·9719	224·9701	482·3862	283·9420
$S(x^2)$	56·8505	225·6714	513·4139	282·5219
$S(y^2)$	63·3395	234·4163	488·5014	297·7558
n	37	116	147	153
$\bar{y}=a$	1·171	1·326	1·728	1·289
b	0·912	0·986	0·623	0·947
r	0·918	0·816	0·645	0·838
s_y	0·2368	0·2983	0·4514	0·3098
s_a	0·0389	0·0277	0·0382	0·0112
s_b	0·0672	0·0653	0·0629	0·0524
y when x=0	0·17	0·02	0·63	0·08
P for x=y=0	0·05—	0·8+	0·001	0·7+
P for b=1	0·2+	0·8+	0·001	0·3+

Comparison of regression coefficients of A and B: d=0·074, s_d=0·094, t=0·79. P=0·4—0·5. Line A+B is y—1·289=0·947 (x—1·272).

The regression coefficients of A and B do not differ significantly from 1; B passes through the origin, whilst the deviation of A from this point is probably not significant with the possibility of error being quite large. The lines A and B are therefore combined and the data plotted in fig. 2. The combined line does not differ significantly from y=x, and shows that, using this method, a good estimate of the population present can be obtained, when only weevils and one or two associated species of beetle are present. The equation C differs significantly both in slope and position from expectation, and this must be caused by the extra errors involved in the data giving this line. These errors include the practical ones made during the development of the method, and those caused by the use of small bottles. Equation B shows that these can be overcome. The other errors have been made in computing the figure for "weevils" bred out from the actual insects obtained; the conversion figures which should be used for *Tinea* larvae and weevil parasites being very uncertain.

An important use of the CO_2 method is to show when a sample is "clean," *i.e.* uninfested by insects, and suitable for prolonged storage. Examination of the numbers of insects bred from samples predicted to be clean shows the performance of the method.

	Total.	Percentage of Total.
Total number of samples predicted to be clean	164	100
Number of samples actually clean (*i.e.* NO insects whatever emerged) ...	109	66·5
Number of samples from which not more than the equivalent of 2 weevils per lb. (4 per kg.) emerged	45	27·5
Number of samples from which more than the equivalent of 2 weevils per lb. emerged.	10	6

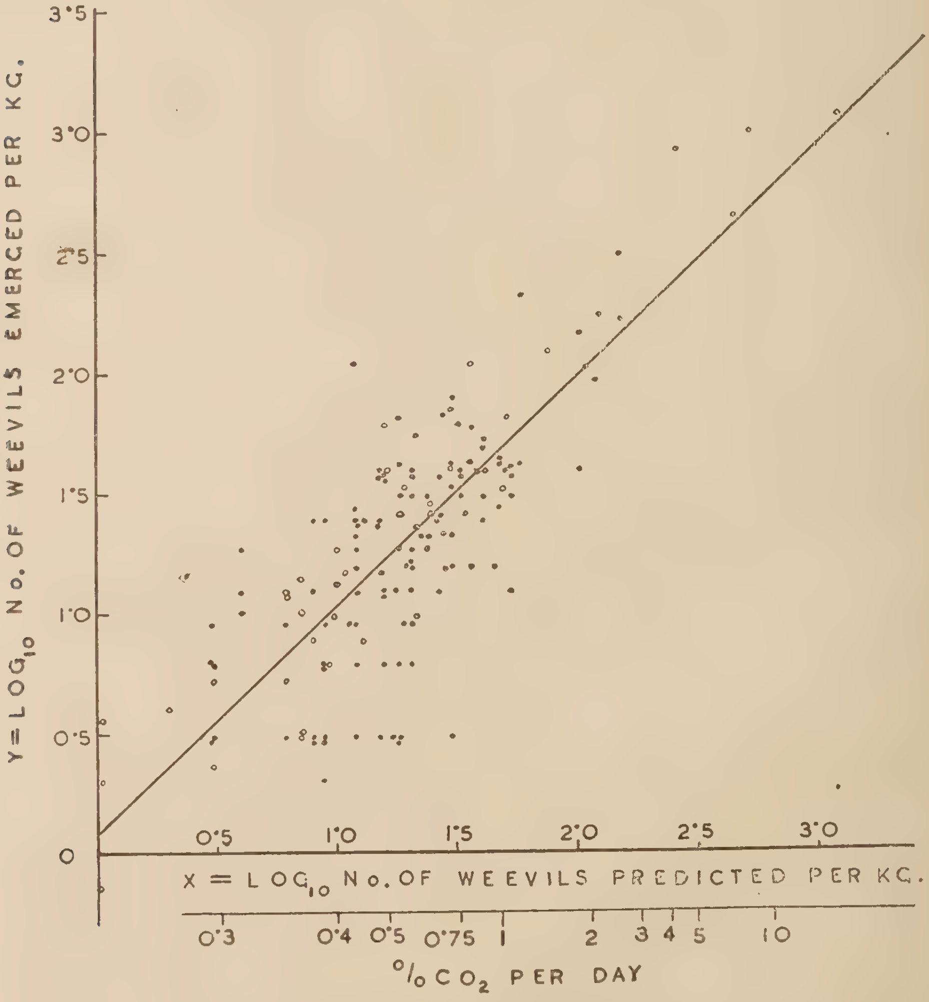

Fig. 2.—Regression line of log, emerged no. of " weevils " against log, predicted no. of " weevils " for combined data of sets A and B. Data from both sets are plotted as a scatter diagram ; each observation is recorded as a point, set A by o and set B by ●.

The occurrence of as many as 6 per cent. of definite errors as shown above appears to indicate that a positive indication of less than two weevils per lb. cannot be made. All these errors, however, were obtained using 60 g. samples, and were almost certainly due to leaks of air into the gas sample taken for analysis. In practice, such an occurrence is usually detected, and with larger samples a check can be made by analysing a fresh gas sample. Complete absence of insects cannot be guaranteed, for one-quarter of the samples contained a little insect life which escaped detection. The emerging insects on these occasions were usually one or two *Laemophloeus* or *Silvanus,* but sometimes very young stages of weevil and other larger insects were not detected. These insects have a low carbon dioxide output, but if sufficient were present to damage the grain, the figures given on p. 14 would be exceeded by the samples containing them. The proportion of clean samples in our data is much lower than it would be in commercial practice, since all the samples we have tested have been drawn from bulks of grain known to be infested, at least in parts.

The number of samples in which a positive indication of infestation has been given by the CO_2 method and from which no insects have emerged is about twenty (4 per cent. of total samples). High water content of the tested grain is the usual cause of such high results from clean grain, but insufficient airing of the grain or bottles is known to have been the source of the error on one or two occasions. It should be noted that commercial samples from grain bulks are usually, for convenience, taken from the surface. In this country, particularly in winter, such grain is often damper than the main bulk and we have found it advisable to allow 0·5 per cent. CO_2 for the respiration of clean grain with such samples.

The above data includes all the results obtained during the development of the method and probably underestimates the precision with which an infestation can be estimated. At present, it is recommended that the method be used as a routine, using the data given on p. 14, to determine how long the various bulks of grain should be left undisturbed. In the spring, it can be used to find if a previous infestation has survived the winter, or if an apparently clean bulk contains the young stages of weevil and hence a growing and potentially dangerous infestation.

Summary.

1. A detailed technique is described for the routine determination of the carbon dioxide output of samples of grain. The concentration of carbon dioxide produced in the intergranular air during incubation for 24 hours at 25°C. is known as the "carbon dioxide figure" of the sample.

2. Suggestions for relating the carbon dioxide figure to potentialities for future storage are given. A high carbon dioxide figure indicates that the grain is unsuitable for storage.

3. The carbon dioxide figure is largely a measure of insect infestation of the sample and a table is given by which the numbers of various species of insects common in grain may be estimated from the carbon dioxide figure.

4. Theoretical considerations affecting the carbon dioxide figure are discussed as far as available knowledge permits.

5. Data obtained in the laboratory during development of the method are presented, and show it to give a useful measure of the amount of infestation.

This work forms part of the programme of the Pest Infestation Laboratory. Thanks are due to Dr. Lucas for making an independent test of the method and for allowing us to use his data.

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THE BIONOMICS OF THE NEOTROPICAL CORNSTALK BORER, *DIATRAEA LINEOLATA*, WLK. (LEP., PYRAL.) IN TRINIDAD, B.W.I.

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The genus of Pyralid (Crambid) moths to which *Diatraea lineolata* belongs is one of considerable size, containing fifty-one described species from the New World (Box, 1931, 1935*a*), and together with the Old World genus *Proceras* which, according to Tams (1942), should be regarded as distinct from *Diatraea*, includes a fairly large number of major pests of cultivated grass crops in both hemispheres, the most notorious being *D. saccharalis* (sugar-cane moth-borer).

Several species of *Diatraea* are known to attack maize, and they include *D. saccharalis*, F., throughout the American tropics and sub-tropics from the southern United States to northern Argentina ; *D. crambidoides*, Grt. (*zeacolella*, Dyar), in the south-eastern United States ; *D. grandiosella*, Dyar, in Mexico and the south-western United States ; *D. dyari*, Box, in Argentina ; and *D. lineolata*, Wlk., in the Neotropics. In the Old World, the species of *Diatraea* (*Proceras*) attacking maize are : *D. sacchariphaga*, Bojer, in Mauritius (as *D. venosata*, Wlk., De Charmoy & Gebert 1921, and as *D. mauriciella*, Wlk., Vinson 1942) ; *D. argyrolepida*, Hamps., in Tanganyika ; and *D. polychrysa*, Meyr., in Malaya.

In Trinidad, seven species of *Diatraea* are known, of which *D. lineolata* and *D. saccharalis* attack maize, the former being confined to maize and teosinte (*Euchlaena*), while the latter has a wide range of host grasses.

The life history of *D. lineolata* in Trinidad maize is very similar to that of *D. saccharalis*, and therefore the two species will be dealt with together. The salient features have already been discussed by Hynes (1942) and Kevan (1943). Field observations helped to fill in certain points not determinable in the laboratory, but otherwise, the data were obtained from specimens reared in glass jars, using the same technique as that of Hynes (1942). Ten—though not always the same ten—examples of each species were taken to furnish the data, the larvae reared being from eggs laid by females bred out in captivity. In the case of the egg-counts for *D. saccharalis*, only three examples were recorded. Egg-clusters were found only very rarely in the field, though it is difficult to say why this should be so. The full data on which the figures given below are based, are given in an unpublished report in the library of the Imperial College of Tropical Agriculture, St. Augustine, Trinidad, B.W.I.

Adult Stage.

The adult moth of both species is very short-lived, the female living from three to five days in each case, averaging 3·9 days in *D. lineolata* and 4·0 days in *D. saccharalis*. The males live for an even shorter period, averaging 2·8 days in *D. lineolata* and 2·7 in *D. saccharalis*. Adults are seldom seen in the field but may sometimes be taken at light.

Both copulation and oviposition, although not observed, undoubtedly ake place at night, and, judging by the appearance of fertile eggs, the former takes place within a few hours to about 1½ days after emergence from the pupa, the eggs presumably being laid almost immediately afterwards. The females would not seem to lay more than one batch of eggs, but it is not known whether the males are capable of fertilising more than one female. Eggs may be laid by unmated females (reared in isolation), but such eggs are sterile.

Egg Stage.

The eggs are laid on the upper leaves of the maize, or later on the young cob-sheaths, in irregular clusters. The eggs themselves are round-oval and flat, measuring just under 1·25 mm. long by about 0·75 mm. across, minutely reticulate, and at first are pale waxy yellow in colour (those of *D. saccharalis* being somewhat paler). In the clusters, the eggs overlap like scales, the smaller clusters being irregularly rounded while the larger ones are more elongated, being up to 12 mm. or more long.

In the laboratory the total number of eggs laid by a single female *D. lineolata* was found to be from 187 to 448, with an average of 377·5, while in the case of *D. saccharalis*, the figures were from 189 to 416, averaging 333·3. The average number of eggs per cluster varied from 2·7 to 21·3, with a mean of 8·96, in *D. lineolata*, and from 4·1 to 18·0 with a mean of 10·1, in *D. saccharalis*.

Of the eggs of *D. lineolata* laid in the laboratory, an average of only 76·7 per cent. formed embryos. Moreover, an average of 14·4 per cent. of the eggs that contained embryos failed to hatch, so that in the clusters under observation, only 62·3 per cent. of the total produced young larvae. Similar figures for *D. saccharalis* were not obtained.

Two days after oviposition, the eggs of *D. lineolata* develop two and a half to three broad, irregular, bright red, transverse bands, and on the third day the U-shaped embryos may be identified within the shells, their black heads being very conspicuous. In *D. saccharalis* the banding tends to be obscure or obsolete, and the eggs have a dull reddish appearance.

Larval Stage.

On the fifth day after oviposition, the larvae emerge from the colourless shells which quickly become detached from the leaf and blow away. Hynes (1942) notes that the eggs of *D. lineolata* hatch in three days after the appearance of the red bands, while Pickles (1936) gives the hatching period of *D. saccharalis* on sugar-cane as six days. The subsequent behaviour of the young larvae has already been briefly discussed by Hynes (1942) and Kevan (1943).

In the young maize—that is, before the appearance of the tassel—the minute larvae at first skeletonise small patches of the leaf, and in a day or two, walk down to the "throat" of the plant, where they burrow into the terminal bud, very frequently reaching the young tassel, when a few of the young male flowers are destroyed. When the leaves of the terminal bud subsequently become unfurled as the plant develops, the presence of *Diatraea* is indicated by the characteristic transverse rows of tiny holes, which, except for their regular conformation and minute size are comparable with those made by *Laphygma frugiperda* (Kevan, 1943). When these holes are seen in the lower leaves of a maize plant, this indicates that it has been infested for some time—that is, since the lower leaves were in the terminal bud—and when they are seen to occur only in the upper leaves, that the attack is quite recent.

After tasselling, the early attentions of the young larvae seem to be directed chiefly towards the young cob-sheaths, where they skeletonise small patches and then burrow into the sheaths. Sometimes such larvae spend the rest of their lives in the cobs, but usually, as is the case with the larvae in the terminal buds, they migrate down the outside of the stem for a shorter or longer distance to a leaf-sheath under the protection of which they commence to bore into the stem, tunnelling either upwards or, more usually, downwards. Seldom, if ever, do larvae of earlier instars than the third begin to bore into the stem.

When the larvae begin by tunnelling upwards, they frequently meet the stalk of the ear, and, if the ear be young, they may reduce it to a rotting mass. Should the ear be older and its stalk drier, a normal tunnel up the centre of the cob results. Usually, however, the borers follow the main stem and avoid that of the ear. Hynes (1942) notes that *D. saccharalis* may occasionally destroy a few actual grains after the manner of *Heliothis armigera*, but it is very doubtful if *D. lineolata* ever does this. Such few examples of this type of damage as have been seen by the writer have all proved to be *D. saccharalis*.

The burrows formed by the larvae are for the most part continuous, but frequently, particularly in the earlier instars, the larvae will leave their burrows, which in such cases are usually quite short, and re-enter the stem elsewhere. Such larvae have been observed in transit on more than one occasion by the writer. As the larvae bore into the stem, they make holes at intervals to the outside, and through them frass is pushed, the masses of which may be quite conspicuous. The larvae, pupae and burrows of *D. lineolata* have already been figured (Kevan, 1943).

There are six to eight larval instars, averaging 7·0 in *D. lineolata* and 7·2 in *D. saccharalis*. This was determined by keeping ten larvae of each species, from the third instar onwards, in short lengths of maize stalk, split down the centre and held together by elastic bands. This allowed the larvae to be examined daily and the number of exuvial head-capsules to be counted. The first three instars were reared on small pieces of leaf. Pickles (1936) gives eight larval instars (seven ecdyses) in the case of *D. saccharalis* in sugar-cane. Freshly moulted larvae are white (including the head-capsule) and unspotted, but they rapidly attain their normal colouration. Fully grown larvae measure between two and three centimetres in length. In the laboratory, the larval stage lasts from 22 to 48 days, averaging 31·2 days, in the case of *D. lineolata*, and from 21 to 50 days, averaging 32·8 days, in *D. saccharalis*.

Pupal Stage.

When the time for pupation arrives, the larva makes a chamber at the end of its burrow and, in most cases, cuts an exit hole to the outside, leaving only the epidermis of the stalk through which the adult, when it emerges, is able to force its way. Occasionally the last frass hole serves as an exit. After the exit hole is cut, the larva loosely lines the chamber with silk and enters the prepupal state, resting head upward, the spots becoming obscure and the body contracting somewhat. Thus it remains for two to five days, occasionally for longer periods, without feeding, and then pupates.

The duration of the pupal instar in *D. lineolata* is from 6 to 13 days, averaging 9·7 days. In maize in the laboratory, the pupal period of *D. saccharalis* varied between 6 and 10 days, averaging 7·4 days. When the moths emerge, the pupa-case is usually left behind in the chamber, but frequently it is dragged through the exit hole, where it may remain half projecting or fall to the ground.

Resting Stage of the Larva.

In dry stalks, the larvae of *D. lineolata*, unlike those of *D. saccharalis* which only seem to attack the young maize plants, enter a resting stage during which they lose their spots, and may moult once or twice more (Hynes, 1942). These resting larvae remain quiescent in the stalks throughout the dry season, pupating with the onset of the rains some months later, and thus the species is able to carry over the period during which the host plant is absent. The existence of this resting stage was first demonstrated by Hynes (1942), who points out that it is characterised by the complete absence of spots and the uniform butter yellow colouration. He seems diffident of using the term " diapause " for the phenomenon exhibited by these larvae, owing to the fact that they moult, remain active and may grow. While yellow larvae certainly feed and grow somewhat, this appears to be true only of the early stages of the resting period, when their behaviour is almost normal. They feed little, if at all, however, in the later stages, becoming inactive and somewhat resembling prepupae in appearance. Although they moult once or twice, they do not seem to increase in size after this, and in fact, if kept in a resting condition for long periods, they actually decrease slightly on moulting.

The term " diapause " (which includes hibernation and aestivation as well as other periods of suspended developmental activity) as proposed by Henneguy (1904) covers " periods of arrest in ontogenic development of an animal from the fertilization of the egg to the adult stage," and his definition is widely accepted. Shelford (1929), however, suggests that diapause or dormancy—he regards the two terms as synonymous—should be restricted to cases in which the activity or development is arrested spontaneously ; cases in which the interruption of activity or development is controlled by unfavourable factors, he would merely designate as quiescent stages. If Henneguy's definition be accepted, then the larvae of *D. lineolata* certainly undergo a diapause, but if Shelford's modification is preferred—as it is by Wigglesworth (1939)—then Hynes' diffidence is justified (though not for the reasons put forward by him), since the resting period is induced and broken by environmental conditions as shown below.

Roubaud (1922) adopts Henneguy's definition, but adds that " this term yields nothing from which to conjecture the nature or physiological causes of the phenomenon," and dealing with cases of hibernation in Muscid larvae, he notes the necessity for the distinction later put forward by Shelford (1929). He proposes the term " homodynamic " for insects in which a period of inertia is not essential for their further development ; a mere return to favourable conditions being sufficient to break the period of quiescence.

The resting stage of *D. lineolata* does not occur independently of environmental conditions, as is the case in many examples of overwintering insects in temperate regions, such as the larvae of the codling moth (*Cydia pomonella*) and the woolly-bear caterpillar (*Isis isabella*), since the yellow larvae may be found in maize stems in the correct condition, both in the wet and dry seasons in Trinidad. There is no periodicity corresponding with the dry season in *D. lineolata*, the life-cycle being homodynamic, and the term " diapause " in its restricted sense cannot be used to cover its resting period.

The importance of contact moisture and high humidity in relation to the resting stages of various insects has been discussed by several authors. Townsend (1926) has made the observation that hibernation in cold-blooded animals is often marked by a reduction in the water content, and the break-up of dormancy is usually marked by the taking in of water. His experiments on the larvae of *Cydia pomonella* showed that the break-up of dormancy was aided by the addition of contact moisture to the tissues, such as normally occurs during rains, and this, he suggests, causes a speeding up of enzyme reactions resulting in pupation—Townsend's Water-Enzyme Theory.

Babcock (1927), discussing the dormant period in the European corn borer (*Pyrausta nubilalis*), found the larvae to be very sensitive to changes in contact moisture, retardation of pupation following desiccation, while Squire (1937), working on the pink boll worm (*Platyedra gossypiella*), discovered that the resting stage—he uses the term " diapause "—in that species is induced by dry and/or rich food towards the end of the crop, irrespective of the time of year, and that the addition of water to the tissues of resting larvae usually causes them to pupate. The position with regard to *D. lineolata* in Trinidad, closely resembles the findings of Squire (*loc. cit.*), and Hynes (1942) has already made some observations concerning it.

As has already been pointed out above, the resting stage does not make its appearance until after the maize plants are mature and have ceased to grow. By the time that the stalks are dry, no spotted larvae remain.

They may also lose their spots and become butter yellow during the rainy season. Spotted larvae may also be found during the dry season in maize grown under irrigation if the plants are young enough. It is also interesting to note that in the particular dry-season crop in question, the maize was scarcely attacked at all, presumably due to the absence of adult moths in the field, there being no other maize in a suitable condition nearby to produce them.

Rainfall does not influence the initiation of the resting stage, since the yellow larvae made their appearance during the investigations several weeks before the end of the rains. Relative humidity varies with the rainfall, and like it, has no direct bearing on the initiation of the resting stage. These observations indicate that it is the condition of the maize stalks themselves that determines whether the larvae will enter the resting stage or not.

The findings of Strel'nikov (1936) and Squire (1937) suggest that dry and/or rich food are the cause of dormancy in *Loxostege sticticalis* and *Platyedra gossypiella*, and according to the former author, dry food induces diapause because the amount of moisture required to build up protoplasm is not present, and what water there is, is bound by it. Rich food increases the tendency to bind free water. It is not certain whether it is the drier food—as suggested by Hynes (1942)—resulting from the ripening of the stalks, or the drier environment, or again, a change in the chemical nature of the food which is the initiating factor, though it is true that if spotted larvae are transferred to moistened " dry " stalks from green ones, they will usually lose their spots and become yellow, which would indicate that the chemical change in the ripening of the stalks was the most important one. Larvae in green stalks that have been allowed to become rotten in the laboratory will also lose their spots, which would add weight to this suggestion, but it may be added that larvae that wander away from the food provided, enter a prolonged resting stage even under humid conditions, suggesting that it is the lack of suitable food—in this case the total lack of food—rather than the food itself which is the cause.

That malnutrition—from lack of food—tends to induce dormancy in the larvae of *Lucilia sericata* has been indicated by Cousin (1929, 1929*a*, 1930), and Baumberger (1914), referring to the larvae of *Cydia pomonella*, considers that " hibernation is usually concomitant with overfeeding " which he suggests is equivalent to malnutrition.

Whatever the cause of the resting stage, however, it only affects larvae over half-grown, and only very seldom any less than three-quarters grown.

The duration of the resting stage may be quite short, or indefinitely prolonged, depending on the nature of the environment, some larvae pupating within a few weeks of assuming the yellow colouration, while others will remain quiescent for months. One larva was kept without appreciable change in a piece of dry maize stalk from mid-September 1942 till the middle of April 1943—when it was accidentally destroyed—a period of seven months. During this time, it moulted twice and decreased slightly in size. It did not appear to feed at all after the first few weeks, and seemed as though it would remain dormant indefinitely.

The break-up of dormancy is apparently brought about by the addition of contact moisture to the tissues of the larvae, as was found to be the case in *Cydia pomonella* by Townsend (1926) and in *Platyedra gossypiella* by Squire (1937). Hynes (1942) has already shown that water is important in causing the resting larvae of *D. lineolata* to continue their development by pupating, and a further small-scale experiment was carried out by the writer, using the same technique, beginning on 2nd March, 1943, and using thirty resting larvae.

Ten larvae were placed in dry stalks in a dry atmosphere, ten in wetted stalks in a saturated atmosphere, and the remainder in a saturated atmosphere without stalks. The results are given in Table I, and it may be seen that only in the wetted

TABLE I.

Date of examination	Number of larvae that had pupated		
	Dry stalks with dry atmosphere	Wetted stalks with saturated atmosphere	Saturated atmosphere without stalks
2nd March	0	0	0
9th March	0	1	0
16th March	0	3	0
23rd March	0	1	0
30th March	0	2	0
6th April	0	0	0
13th April	0	0	0
20th April	0	0	0
Total	0	7	0
No. of larvae that died	1	2	2
No. of larvae remaining alive	9	1	8

stalks was dormancy broken. The larvae in the saturated atmosphere without stalks merely climbed to the tops of the jars and remained there. This small experiment suggests that contact moisture rather than humidity is the initiating factor, and a further small-scale experiment to test out this suggestion was made, beginning 4th March.

Twenty resting larvae were put each in an inverted 2×1 in. specimen tube without food. Ten of these were placed over anhydrous calcium chloride in a desiccator, resting on perforated zinc, and the remaining ten were placed over moist sand in a closed glass container. Five of these latter were separated from the sand by a layer or two of blotting paper about half way up the tube to prevent them from coming into contact with the free moisture of the sand should they not remain at the tops of the tubes. Five of the larvae in the desiccator, *i.e.* with very low humidity, and five of the larvae over the moist sand—high humidity; those not separated from the sand by blotting paper being selected—were sprayed daily with water from an atomizer.

The results are given in Table II.

Only one of the sprayed larvae and none of the unsprayed ones in the dry atmosphere pupated—two in each case succumbed to the drastic treatment. The surviving unsprayed larvae continued to exist without change in the desiccator till the end of May 1943, when they were still healthy though somewhat reduced in size. In the humid atmosphere, all three surviving larvae receiving contact moisture from the atomizer, pupated within five weeks, while only a single unsprayed larva pupated—in this latter case, the reason for pupation may possibly have been that insufficient precautions were taken to prevent contact with a moist medium, the blotting paper having become sodden, and the particular larva in question not having remained at the top of the tube.

The two experiments described, though by no means exhaustive or conclusive, would suggest that contact moisture is the most important factor in the breaking up.

TABLE II.

Date of examination.	Number of larvae that had pupated			
	Low humidity		High humidity	
	With contact moisture	Without contact moisture	With contact moisture	Without contact moisture
4th March ...	0	0	0	0
11th March ...	0	0	0	0
18th March ...	0	0	0	0
25th March ...	0	0	2	0
1st April ...	0	0	0	0
9th April ...	0	0	1	1*
15th April ...	0	0	—	0
22nd April ...	1	0	—	0
Total ...	1	0	3	1*
No. of larvae that died ...	2	2	2	1
No. of larvae remaining alive	2	3	0	3

* In contact with damp blotting-paper.

of dormancy. A high relative humidity would not appear to be necessary, and a high humidity alone is probably not sufficient to bring about the break-up. The condition in the field, however, does not involve the question of low humidities, since in Trinidad, humidity is always high, even during the dry season.

The coming of the rains has been shown diagramatically by Hynes (1942) to result in the continued development of the resting larvae by causing them to pupate, owing, no doubt, to the sodden condition of the previously dry stalks. The same has been found to be the case by the present writer (Kevan, 1943), and it should be noted that the first rains do not bring about the resumption of developmental activity. There is a lag until the stalks become thoroughly sodden.

During the rainy season, when resting larvae may also be found, stalks would become sodden fairly soon after harvesting, and the resting period when it occurred, would, in consequence, be short. An investigation of this point, however, has not been made.

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AIR TEMPERATURE RECORDS AS A GUIDE TO THE DATE OF HATCHING OF THE NYMPHS OF *AUSTROICETES CRUCIATA*, SAUSS. (ORTHOPTERA).

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Introduction.

In South Australia *Austroicetes cruciata* has only one generation a year (Andrewartha, 1939). The presence of an obligate diapause in the egg-stage ensures that the embryo does not complete its development until after the winter (Birch, 1942, Andrewartha, 1943). This is an important adaptation in a climatic zone where the spring is the only period of the year when there is likely to be an abundance of green feed, at a time when temperature is favourable to the insect.

In the grasshopper belt the spring is short ; in most years the plants upon which the grasshoppers feed dry up during November ; and the grasshoppers have usually died out from all but a few local favourable situations by the end of this month or early in December. During the most recent outbreak of *A. cruciata* in South Australia, which lasted from 1935 to 1940, the nymphs usually hatched during the first half of September ; egg-laying began late in October or early in November, and ceased late in November or early in December. Precise information on the date of occurrence of these events was not obtained since observations were restricted to what could be done on a number of survey trips spaced at irregular intervals, but approximate dates were established for the latter years of the outbreak ; they are given below (Table I).

TABLE I.

Showing approximate date of hatching of nymphs at Hammond.

	1937	1938	1939	1940
Approximate date nymphs hatched ...	—	8th Sept.	16th Sept.	25th Aug.
,, ,, egg-laying began ...	3rd Nov.	1st Nov.	30th Oct.	—
,, ,, egg-laying ceased ...	25th Nov.	3rd Dec.	20th Nov.	—

It is not known how many eggs a grasshopper may lay in the field. Dissections indicate that the potential number of eggs is 270 ; this is equivalent to about 14 egg-pods.* Field observations suggest that this potential is never reached. Almost always the food supply dries off and the grasshopper dies from starvation before laying this number of eggs. In some years the spring may be so dry and the growing period for the plants so short that most of the grasshoppers die without reaching the egg-laying stage ; it is estimated that this has happened four or five times in 50 years (Birch & Andrewartha, 1941). In most years a large proportion of the grasshoppers survive to lay some eggs. The number of eggs laid depends largely upon the duration of the life of the grasshopper during the egg-laying stage.

Since the termination of egg-laying is normally brought about by the food plants drying off and the consequent death of the grasshoppers, it is clear that rain which may fall in the late spring and early summer and thus prolong the growth of the plants is the most important factor influencing the date on which egg-laying ceases.

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* Data from an unpublished thesis by L. C. Birch.

On the other hand, the time when egg-laying begins depends upon the time when the eggs hatch and upon the rate of development of the nymphs.

In this paper the date of hatching of the eggs in the field has been estimated for each of the 51 years between 1892 and 1942. A new method has been developed for the evaluation of the influence of temperature, recorded in the field, upon the rate of development of the eggs. This was necessary because it was shown that large and important errors are inherent in the conventional method of temperature summation which makes use of mean daily temperature and assumes that the relationship between temperature and rate of development is linear over the range of temperature used for temperature summation.

Methods for Analysing Temperature Records.

A. *Sources of error.*

In ecology, when it is required to evaluate the influence of temperature, it is usually necessary to work with records of maximum and minimum temperature taken in standard meteorological screens. It is usual to estimate the mean daily temperature by calculating the arithmetic mean between the minimum and the maximum. If this mean daily temperature is then used to estimate the mean rate of development per day from the curve relating temperature to the rate of development of the organism, the following sources of error may be introduced :—

(1) The temperature in the screen may differ from that in the micro-environment of the organism.

(2) The arithmetic mean of the maximum and minimum temperature may not be an adequate estimate of the true mean temperature for the day.

(3) The relation between the rate of development of the organism and the temperature, over the range of temperature used, may not be linear.

(4) When the minimum temperature for the day is lower than the lowest temperature at which appreciable development occurs in the organism, development goes on for less than 24 hours in the day. Thus it is inaccurate to base estimates of the rate of development on the mean temperature for the whole day.

These four sources of error have been considered in sequence, with particular reference to the influence of temperature on the rate of development of the egg-stage of the grasshopper.

1. *The temperature in the micro-environment.*

The eggs of *A. cruciata* are laid in the soil at a depth of about 1 inch. In South Australia hatching takes place during September ; post-diapause development of the egg begins early in June (Birch, 1942).

None of the meteorological stations in the grasshopper belt takes soil temperatures ; but records have been taken at the Waite Institute for 16 years. The Waite Institute is situated about 150 miles south of the grasshopper belt. In Table II the temperature of the soil at the Waite Institute at a depth of 1 inch is compared with the temperature of the air in a standard screen, for the months June to October.

Both the mean daily and the maximum temperature at 1 inch below the soil surface (where the grasshopper eggs occur) are higher than the temperature of the air in a standard screen ; but the difference is not the same for all months (Table II).

2. *The mean daily temperature.*

The arithmetic mean of the maximum and minimum temperature gives only an approximate estimate of the true mean daily temperature. The curve traced on the thermograph on a cloudless day approximates to a sine curve (Craig, 1941). With cloud or intermittent sunshine the curve may be irregular. The true mean daily

TABLE II.

Showing monthly means for maximum and mean daily temperature for air and 1 *in. soil at the Waite Institute. Based on* 16 *years' records.*

Month	Max. Temp. F.			Mean Daily Temp. F.		
	Soil 1 in.	Air	Difference	Soil 1 in.	Air	Difference
June	63·7	58·6	5·1	55·4	52·5	2·9
July	62·0	57·3	4·7	54·1	51·3	2·8
August	65·6	59·0	6·6	56·4	52·4	4·0
September	74·0	63·6	10·4	62·1	55·9	6·2
October	85·1	68·8	16·3	69·9	60·0	9·9

temperature is given when the area bounded by the thermograph curve, the zero line, and the ordinates delimiting the day, is divided by the distance between these ordinates; both the area and the distance must be expressed in appropriate units, *viz.*, hour-degrees and hours respectively.

This graphical method was used to determine the mean daily temperature of the soil at the Waite Institute at a depth of 1 inch for 224 days in the months of June, July, August and September for the years 1938 and 1939. A planimeter was used to measure the area beneath the thermograph curve. Each determination was the mean of four runs with the planimeter. A preliminary test showed that it was possible to determine the temperature within ±0·15°F. An important source of error was the thickness of the line traced by the thermograph pen. The full period from midnight to midnight was not necessarily used for every day, but only that period which was above 54°F. This was taken as the temperature below which no appreciable development occurs in the eggs of *A. cruciata, i.e.* temperatures above 54°F. were considered to be effective for growth (Birch, 1942).

In Table III, columns B and C, the mean daily " effective " temperature for the month as determined with the planimeter is compared with the estimate given by taking the arithmetic mean of the maximum and minimum for that part of the day during which the temperature exceeded 54°F. This latter estimate involves an error of from 0·60° to 1·24°F. (column D). This error occurs because the temperature is not changing at a uniform rate, *i.e.* the thermograph pen does not trace a straight line; it is, of course, smaller when the interval between maximum and minimum is smaller. In columns B and E the comparison is between the readings given by the planimeter and the estimate obtained by dividing the day into two-hour periods and taking the arithmetic mean of the maximum and minimum temperature for each two-hour period. By this method the error was reduced; it varied from 0·04° to 0·38°F. with a mean of 0·26°F. for all the months.

Thermograph records for 301 days were examined for the months June, July, August and September for the years 1938, 1939 and 1940. The greatest difference between maximum and minimum temperature for any one day was 35°F. It was greater than 5°F. for 88·4 per cent. of the days, greater than 10°F. for 50·2 per cent. of the days and exceeded 15°F. for 24·9 per cent. of the days. For the same period the records of maximum and minimum temperature for 1,670 two-hour periods were examined. The greatest difference between maximum and minimum temperature was 18°F.; it was greater than 5°F. for 29·5 per cent. of the cases and greater than 10°F. for 18·2 per cent. of cases.

TABLE III.

Showing monthly means for "effective" temperature as determined by the planimeter, and estimates based on daily and 2-hourly intervals. Only that part of the day during which the temperature exceeded 54°F. was considered.

A Month		Mean Temperature 1 in. Soil °F.				
		B Planimeter	C $\frac{\text{Max}+54}{2}$ daily	D Difference B−C	E $\frac{\text{Max}+\text{Min}}{2}$ 2-hourly	F Difference B−E
1938	June	57·82	57·22	+0·60	57·50	+0·32
	July	59·27	58·28	+0·99	59·00	+0·27
	August ...	60·56	59·57	+0·99	60·60	−0·04
	September ...	65·04	64·09	+0·95	64·71	+0·33
1939	June	59·68	58·76	+0·92	59·30	+0·38
	July	58·25	57·56	+0·69	58·08	+0·17
	August	58·67	58·13	+0·54	58·43	+0·24
	September ...	63·83	62·59	+1·24	63·52	+0·31
Mean				+0·87		+0·26

3. *The curvilinear relationship between temperature and rate of development.*

The rate of development of post-diapause eggs of *A. cruciata* in relation to temperature is shown in fig. 1. The curve applies to development occurring after 1st June (Birch, 1942).*

Birch found that the relationship between temperature and the rate of development of post-diapause eggs of *A. cruciata* is not adequately represented by a straight line. The formulae of Vant Hoff, Arrhenius, Belehradek and Janisch, which have sometimes been used to relate temperature to the rate of development, were rejected because it has been shown that these formulae do not adequately express relationship throughout the range of temperature at which development proceeds (Powsner, 1938, Davidson, 1942, 1943).

It has been shown for a number of insects that the Verhulst-Pearl logistic curve expresses the relationship between temperature and the rate of development over most of the range of temperature at which development goes on (Davidson, 1943). With eggs of *A. cruciata* collected on 29th June (when diapause had apparently been completely eliminated), this type of curve gave a good fit to the observed data over 90 per cent. of the temperature range (Davidson, 1942).

For the analysis presented in this paper, data from eggs collected on 29th May were used. It was found that a single logistic curve did not provide an adequate fit for these data. This may have been because diapause had not been completely eliminated from these eggs. However, when two intersecting curves were used the curves fitted the data closely. The curves intersect at 24·1°C. This means that curve A of fig. 1 applies up to 24·1°C., and curve B applies beyond this temperature.

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* Birch's data for eggs collected on 29th May and subjected to a "cold treatment" were used. It can be shown from his data that these eggs, during their "cold treatment" had done 0·08 of the development which they had still to do on 1st June. Consequently his reciprocal values were multiplied by 0·92. This adjustment was made because it was necessary to work with records of mean monthly temperature in making the analysis reported below.

The occurrence of a " break " in the curve at this temperature is of interest in view of the observation that temperatures up to 25°C. had some influence in eliminating diapause from eggs in the late diapause stage (Birch, 1942). It was shown in an earlier paper that the elimination of diapause proceeded most rapidly at 10°C. ; the speed with which diapause was eliminated fell off rapidly above 13°C. ; but it was suggested that temperatures as high as 25°C. may have some influence on this process (Andrewartha, 1943).

The mean rate of development for any period during which temperature is changing at a uniform rate, is given in fig. 1 when the area under that part of the curve cut off by ordinates drawn from the temperature values at the beginning and end of the period is divided by the distance between these ordinates provided that the area is expressed in units of temperature X rate of development, and the distance in units of temperature. If the graph were a straight line, the mean rate of development for the period would be given by the height of the ordinate at the mean temperature for the period. For small intervals of temperature the curvature of the graph may be ignored without introducing appreciable error. For example, for a temperature interval of 5°F. the error was less than 0·5 per cent. ; with a temperature interval of 10°F. it was still less than 2 per cent. for all but the lowest rate of development ; with larger temperature intervals the error may be larger (Table IV). It was shown above that for most of the 2-hour periods which were examined, the temperature interval between maximum and minimum temperature was less than 5°F. ; but for half of the full days examined the temperature interval exceeded 10°F.

TABLE IV.

Showing the mean rate of development for eggs of A. cruciata *for periods with uniformly changing temperature* (a) *measured with the planimeter and* (b) *estimated from the mean of the maximum and minimum temperature* (*ignoring the curvature of the graph*). *All data calculated from fig.* 1.

Mean Temperature for period °F.	Temperature interval °F.	Rate of dev. as % dev. per day		Error " a "—" b " as % on " a "
		measured with planimeter (a)	estimate based on mean temperature (b)	
60	5	1·77	1·76	0·56
65	,,	3·51	3·50	0·29
70	,,	5·55	5·56	−0·18
75	,,	7·72	7·70	0·26
80	,,	10·34	10·30	0·39
85	,,	13·80	13·80	0·00
60	10	1·83	1·76	3·82
65	10	3·56	3·50	1·69
70	,,	5·55	5·56	−0·18
75	,,	7·78	7·70	1·03
80	,,	10·47	10·30	1·59
85	,,	13·74	13·80	−0·44
72·5	27	7·02	6·60	5·95

4. *The influence of the minimum temperature.*

When the minimum temperature is lower than the lowest temperature at which appreciable development occurs, development goes on for less than 24 hours in the day. For any one day the period during which no development occurs becomes longer as the minimum temperature becomes lower. Thus when this source of error is ignored (*i.e.* when estimates of the mean daily rate of development are based on the mean temperature for the whole day), the estimate tends to be too low when the minimum temperature is low and too high when the minimum temperature is high (fig. 2 A). This error was not measured directly but was obtained indirectly as follows. The mean daily rate of development was estimated by three methods described below as "a," "b," and "c."

TABLE V.

Showing the mean rate of development per day for eggs of A. cruciata, *calculated from 2-hourly and daily mean temperature. The mean monthly maximum and minimum temperature at* 1 *in. below the soil surface is also given.*

Month	Mean rate of development as % dev. per day						Mean Temp. 1 in. soil	
	$\frac{\text{Max}+\text{Min}}{2}$ 2-hours (a)	$\frac{\text{Max}+54}{2}$ daily (b)	$\frac{\text{Max}+\text{Min}}{2}$ daily (c)	Difference as % of column (a)			Max.	Min.
				b−a	c−a	b−c		
1938 June	0·35	0·33	0·09	5·7	68·5	62·8	60·3	42·4
July	0·52	0·44	0·18	15·4	65·4	50·0	62·5	44·0
August	0·82	0·68	0·54	17·1	34·2	17·1	65·1	44·0
Sept.	2·22	1·97	2·14	11·3	3·6	−7·7	74·2	47·7
1939 June	0·60	0·54	0·51	10·0	15·0	5·0	63·5	47·4
July	0·44	0·39	0·18	11·4	59·1	47·7	61·2	44·9
August	0·50	0·38	0·26	24·0	48·0	24·0	62·0	43·7
Sept.	1·80	1·47	1·65	12·8	8·4	−4·4	71·3	46·6

(*a*) The mean rate of development per day for each of 224 days in June, July, August and September, 1938 and 1939, was estimated from the thermograph charts using the following three steps :—

(1) Each day was divided into 2-hour periods. The arithmetic mean of the maximum and minimum was taken as the mean temperature for each 2-hour period. (Temperature does not necessarily change at a uniform rate during a 2-hour period but it has been shown above that only a small error is introduced by assuming that it does—Table III.)

(2) The mean rate of development was estimated from fig. 1. The curvature of the line was ignored. It was shown above (Table IV) that for short temperature intervals (of the order 5°–10°F.) the error introduced by ignoring the curvature of the graph is of the order 0–1·5 per cent.

(3) The mean rate of development for each day was found by taking the mean for all the 2-hour periods in the day.

(*b*) Only that part of the day during which the temperature exceeded 54°F. was considered. The mean temperature for this period was taken as the arithmetic mean of 54° and the maximum for the day. The rate of development appropriate to this temperature was read off from fig. 1 and then multiplied by the correction $\frac{\text{hours above } 54°\text{F.}}{24}$ to give the mean rate of development for the whole day. This method ignores the curvature both of the thermograph line and of the curve relating temperature to rate of development.

(*c*) The whole day was considered. The mean temperature for the day was taken as the arithmetic mean of the maximum and minimum. The rate of development appropriate to this temperature was read off from fig. 1. In addition to ignoring the curvature of the thermograph line and the temperature-development curve, this method also ignores the fact that, for those days on which the minimum temperature was below 54°F., there was a period during which no development occurred.

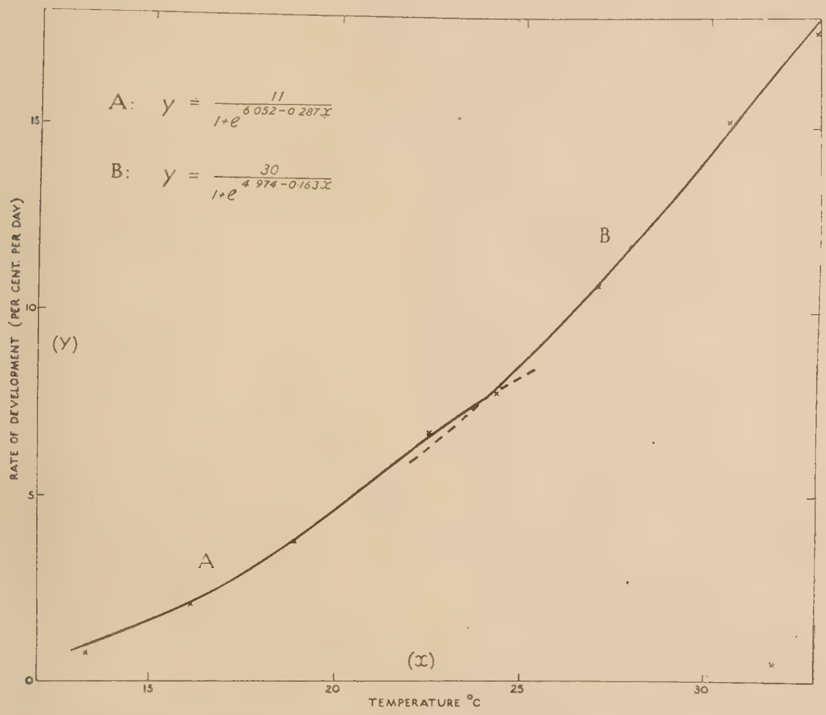

Fig. 1. Relationship between constant temperature and the rate of development of eggs of *Austroicetes cruciata*, collected from the field on 29th May (diapause may not have been completely eliminated from these eggs).

Method "a" excluded errors from sources 1 and 4 and reduced to small proportions errors from sources 2 and 3; method "b" excluded errors from sources 1 and 4 but ignored errors from sources 2 and 3; method "c" excluded errors from source 1 but ignored errors from sources 2, 3 and 4.

The difference between methods "b" and "c" represents the error contributed by source 4; the difference between methods "a" and "b" represents the error contributed by sources 2 and 3; and the difference between methods "a" and "c" represents the error contributed by sources 2, 3 and 4 (Table V).

Method " a " has been considered to give an adequate estimate of the mean daily rate of development and the errors contributed by the other two methods have been expressed as a percentage of the value given by method " a ". It will be seen from column 7 of Table V that the method which used the mean temperature for the whole day under-estimated the rate of development by as much as 62·8 per cent. in a month with a low minimum temperature, and over-estimated it by 7·7 per cent. in another month when the minimum temperature was higher.

B. The use of mean maximum temperature to estimate the rate of development of eggs in the field.

The data for the foregoing analyses were taken from thermograph charts for soil at the Waite Institute at a depth of 1 inch. Thermograph records are not available for stations in or near the grasshopper belt. Nor is it usually practicable for the ecologist to work with thermograph records. Usually these are not available; even when they are available, the work becomes impracticable when a large number of years are involved. It was therefore necessary to work with the usual records of maximum and minimum temperature taken in a standard meteorological screen.

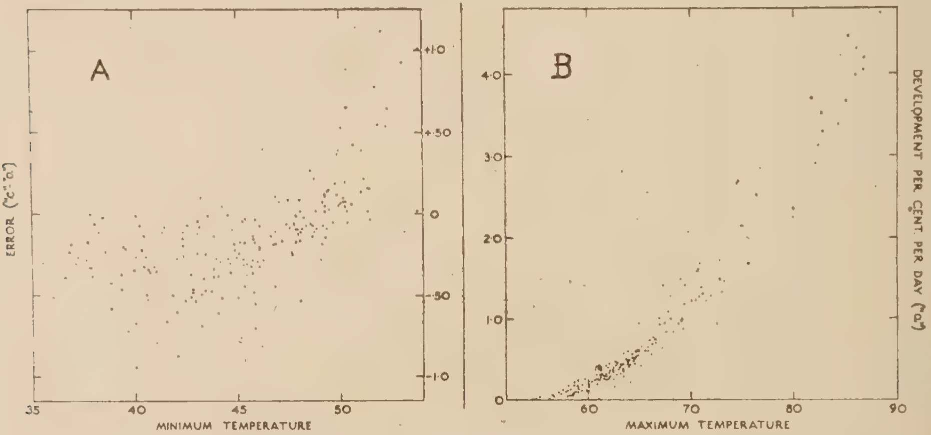

Fig. 2. A. Correlation between minimum temperature and the error in estimates of rate of development which ignore the fact that development may proceed for less than 24 hours a day when the minimum temperature is below 54°F. B. Relationship between maximum temperature and the rate of development. In both A and B each dot represents the data for one day.

It has been shown above that estimates of the rate of development which are based on the mean daily temperature may be grossly inaccurate, particularly when the minimum temperature for the day is lower than the lowest temperature at which development takes place (Table V, and fig. 2 A). On the other hand, there is a sufficiently consistent relationship between the maximum temperature for the day and the mean rate of development for the day (fig. 2 B).*

In evaluating the influence of temperature recorded in the field on the date of hatching of nymphs of *A. cruciata*, it was impracticable to work with daily records, and mean monthly data were therefore used.

The method described under " a " above was used to estimate the mean daily rates of development for the months June, July, August and September for the years

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* This relationship would be absolutely consistent if the thermograph curve were exactly the same shape each day. The inconsistencies are due to variations in the shape of the thermograph curve which are associated with cloud, wind and other meteorological events.

1938, 1939 and 1940 (Table V). These values were then plotted against the mean maximum temperature for the month. It was found that two intersecting logistic curves gave a sufficiently good fit to the data (fig. 3).* This combined curve was used for the analysis which appears in the next section ; it gave dates which agreed satisfactorily with the observations on the date of hatching in the field, made during the 1935–1940 outbreak (Table I).

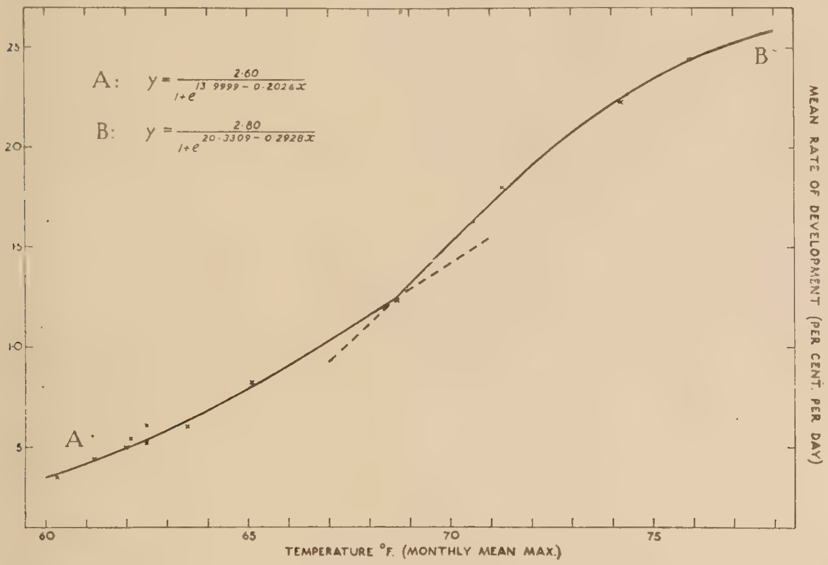

Fig. 3. Relationship between monthly mean maximum temperature and mean daily rate of development for eggs of *A. cruciata* collected from the field on 29th May.

The Estimated Date of Hatching of Nymphs for the Years 1892-1942.

For convenience in analysing records of monthly temperature, post-diapause development was considered to begin on 1st June. It has been shown that diapause disappears early in June (Birch, 1942). In some years diapause may not have completely disappeared by this time, but the minimum temperatures prevailing in June are effective for eliminating diapause ; and maximum temperatures are so low that little growth occurs during this month. It has been shown that normal growth may proceed concurrently with " diapause-breaking " ; abnormalities appear only if the embryo is " forced " to grow excessively with respect to the amount of " diapause-breaking " that has occurred (Andrewartha, 1943).

The influence of temperature on the post-diapause development of the eggs of *A. cruciata* was evaluated for a number of localities in the grasshopper belt. Records of the mean monthly maximum air temperature are available for four stations in or near the grasshopper belt. For other situations temperature was interpolated, allowing 3°F. for each 1,000 feet elevation. The mean monthly maximum air temperature was estimated for June, July, August, September and October for the years 1892–1942 ; the correction given in Table I was added to allow for the fact that the eggs of the grasshopper occur about 1 inch below the surface of the soil ; and then the mean daily rate of development for the month was read directly from fig. 3.

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* These data were also plotted against the mean daily temperature for the month. There was a wide scatter, and it appeared that no curve could be fitted that would adequately represent the trend.

In those cases in which the estimated end-point for development did not approximate to the end of the calendar month, it was considered that the month as a unit was too coarse, and the mean maximum one-inch soil temperature for the appropriate half-month was estimated with reference to the temperature for the month immediately following or preceding. This is best understood with reference to an example. At Hammond in 1922, 65·1 per cent. of the development of the eggs had been completed by 31st August, leaving 34·9 per cent. to be completed during the first half of September. The mean maximum one-inch soil temperature for the first half of September was estimated to be $\frac{67\cdot4+3\times78\cdot2}{4}=75\cdot5$°F., since the temperature for August was 67·4°F. and for September 78·2°F. Fig. 3 gives 2·38 per cent. per day as the mean daily development corresponding to a mean maximum temperature of 75·5°F. This figure was divided into 34·9, giving the estimated date of emergence as 15th September.

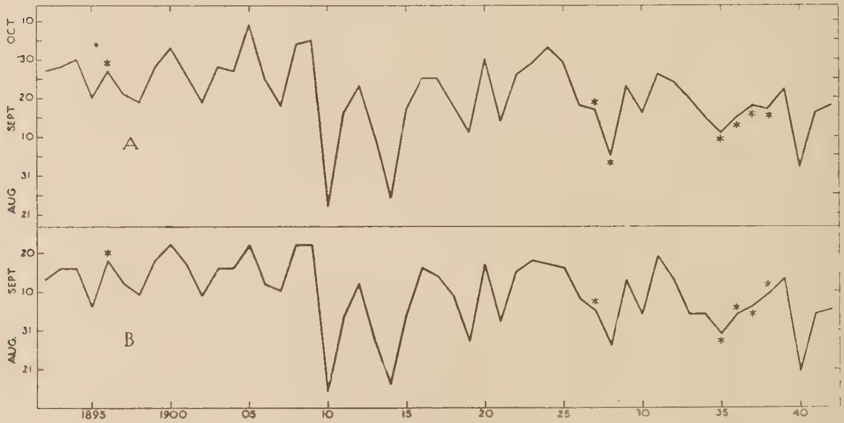

Fig. 4. Estimated date of emergence of nymphs of *A. cruciata* for A, Orroroo, and B, Hammond. The asterisk indicates years in which grasshopper plagues were recorded.

The details of the estimated dates of hatching for two localities are given in fig. 4. Hammond is one of the hotter and Orroroo one of the cooler situations in the grasshopper belt. The calculated dates for Hammond for the years 1937–40 agree sufficiently well with the observed dates given in Table I. Nevertheless it is not considered that this method offers a precise measure of the rate of development of eggs in the field. But the degree of accuracy is sufficient to compare one year with another with reference to the earliness or lateness of hatching of the nymphs.

It was shown above (p. 3) that earliness of hatching was one factor favourable for the multiplication of the grasshoppers. A list of records of grasshopper plagues was given in an earlier paper (Birch & Andrewartha, 1941). These records are probably incomplete ; the absence of records does not necessarily mean that grasshoppers were not numerous. In fig. 4 the years for which grasshopper plagues were recorded are indicated. It will be seen that grasshopper plagues tend to be associated with and to follow years in which the nymphs hatched early.

Summary.

Most of this paper is occupied with the description of a method for evaluating the influence of temperature, recorded in the field, on the rate of development of the

eggs of a grasshopper (*Austroicetes cruciata*). When the conventional methods of temperature summation were used, important errors were introduced because :—

(*a*) The temperature in the environment of the insect may be different from the temperature in the meteorological screen.

(*b*) The arithmetic mean of the maximum and minimum temperature may not be an adequate estimate of the true mean temperature for the day.

(*c*) The relationship between temperature and the rate of development of the organism over the range of temperature used, was not linear.

(*d*) Development may proceed for less than 24 hours of each day.

Working with thermograph records and dividing the day into twelve 2-hour periods, a satisfactory estimate for the rate of development for 224 days was obtained. When these data were combined to give mean daily rate of development for monthly periods, it was found that the mean maximum temperature was a more reliable guide to the mean daily rate of development than was the mean daily temperature for the month. A curve was constructed relating mean daily rate of development to monthly mean maximum temperature.

This curve was used to estimate the date of hatching of nymphs of *A. cruciata* in South Australia for each of the 51 years 1892-1942. The method does not give a precise estimate of the rate of development in the field ; it does provide a useful comparison between one year and another with reference to the general earliness or lateness of hatching in the spring.

Plagues of *A. cruciata* tend to occur in, or to follow, years in which the nymphs hatched early.

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NEW INJURIOUS CURCULIONIDAE FROM AFRICA (COL.).

By Sir Guy A. K. Marshall, K.C.M.G., F.R.S.

The types of the following new species have been deposited in the British Museum.

Subfamily Brachyderinae.

Protostrophus hirtiventris, sp. n. (fig. 1).

♂♀. Derm black, with uniform dense grey scaling that has a coppery reflection.

Head separated from rostrum by a narrow bisinuate stria ; frons depressed below the level of the eyes and separated from them by a deep incision on each side, obliquely striolate and with a deep median sulcus ; eyes moderately convex, extended sharply backwards for about one-third of their length, the orbit not projecting on the hind margin. *Rostrum* very slightly longer than its basal width, widest at base, gradually narrowing for two-thirds its length and thence more rapidly ; dorsum broadly depressed, with longitudinally confluent punctures and a fine median carina. *Antennae* piceous ; scape slightly exceeding hind margin of eye ; funicle with joint 1 nearly twice as long as 2, 3–7 subequal, about as long as broad and slightly widening distally. *Prothorax* nearly twice as broad as long, unusually flat, being only gently convex transversely, widest at the strongly arcuate base, the angles of which project laterally, with the sides almost straight and rapidly converging anteriorly, the apical margin being deeply sinuate on each side behind the eyes ; dorsum flat longitudinally in the middle, densely squamose, each scale covering a minute granule. *Elytra* ovate, broader in ♀, widely sinuate at base, which is marginate, with the lateral angles projecting outwards and forwards, and the sides sinuate behind the angles ; the dorsal outline moderately convex, sloping at the base ; the shallow striae containing close deep punctures, which show through the scaling though partly covered and disappear

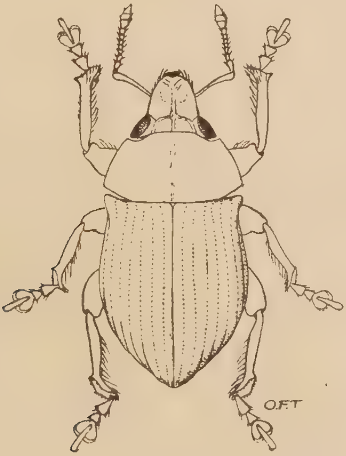

Fig. 1. *Protostrophus hirtiventris*, Mshl., sp. n.

behind, where the striae become deeper ; intervals almost flat, with minute inconspicuous recumbent setae. *Legs* piceous, with dense concolorous scaling and their lower edges with a fringe of stiff erect setae ; front tibiae compressed, with the outer edge carinate and the external apical angle produced laterally, the spines on the apical margin much reduced ; hind tibiae with the inner face flattened and sinuate on the apical half, the corbels bare and ascending the dorsal edge more than usual, with the upper end angulate. *Venter* squamose laterally, but clothed elsewhere with dense stiff suberect setae.

Length, 4·0–4·7 mm., breadth, 2·0–2·5 mm.

South Africa : Weltevreden, 5♂ 1♀, x.1942 (*W. B. Cogan*) ; Crecy, Transvaal, 5♂ 4♀, xi.1943.

Received from the Division of Entomology, Pretoria, with the information that the adult weevils were attacking ground-nut plants (*Arachis hypogaea*), young maize and granadillas.

A very distinct species, coming nearest to *P. funestus*, Pér., but differing from it and its allies in a number of distinctive characters, such as the concave frons and rostrum, the shape and comparative flatness of the pronotum, the very prominent basal angles of the elytra, the hirsute venter, and the structure of the tibiae.

Protostrophus dimorphus, sp. n.

♂♀. Derm black, with uniform dense green scaling (sometimes with a coppery reflection), venter more coppery grey.

Head separated from the rostrum by a deeply curved stria that does not quite reach the eyes ; the very broad frons gently convex in both directions, with a narrow median stria ; eyes very prominent, produced backwards for about half their length, strongly convex, the posterior edge of the orbit not projecting. *Rostrum* strongly conical, much wider at its base than the median length (8 : 5) ; dorsum with a very shallow impression on each side, a broader median depression on the apical half and just behind it a short obtuse squamose longitudinal ridge ; genae not impressed. *Antennae* with joint 1 of the funicle somewhat longer than 2+3, 4–7 transverse. *Prothorax* nearly twice as broad as long in ♂, somewhat narrower in ♀, widest at the projecting basal angles, gradually narrowing anteriorly with more or less of a curve, deeply constricted at apex with a small elevation behind the constriction, forming a recess to receive the backwardly projecting eyes ; apical margin bi-arcuate dorsally, basal margin sub-truncate, with a deep sinuation on each side to receive the projecting basal angles of the elytra ; dorsum strongly convex transversely and slightly so longitudinally, with an abbreviated median stria that is deep near the base and gradually disappears beyond middle, the coriaceous derm entirely concealed by dense scaling and short appressed setae. *Elytra* broadly obovate, widest behind middle and flattened dorsally in ♂, more narrowly ovate, widest at middle and convex dorsally in ♀ ; base truncate, with the angles projecting outwards and forwards ; the shallow striae partly covered by scaling with the small bare separated punctures showing through, striae 1–3 curving strongly outwards at the base ; the intervals broad and flat, with an irregular row of short recumbent setae, the scales round, dense and similar to those on the pronotum. *Legs* with dense grey scaling having a coppery reflection ; front tibiae without distinct apical teeth, corbels of hind pair partly squamose.

Length, 3·5–4·0 mm., breadth 1·7–2·0 mm.

Transvaal : Nylstroom, 2♂ 4♀, x.1943.

The Division of Entomology, Pretoria, report that the adults of this species were found attacking young tobacco plants.

Of nearly 100 species of *Protostrophus* known, this is only the second green one, the other being *P. spinicollis*, Mshl. 1919, which may be distinguished *inter alia* by its much longer and narrower rostrum, the broad median carina on the prothorax and the sharp lateral spine at one-fourth from the base. The sexual dimorphism in the shape of the elytra of the new species is unique in the genus.

Scolochirus, gen. nov.

Head subconical, narrowing from base to apex, with the eyes almost round, large and flat. *Rostrum* at base as wide as and continuous with the head, parallel-sided; epistome distinct, its carinate margin forming a sharp acute angle; mandibles multisetose, without scaling; mentum with a transverse row of four setae. *Antennae* with the scape abruptly clavate, reaching to about the middle of the eye; funicle devoid of scaling. *Prothorax* nearly as long as broad, truncate at base and apex. *Scutelium* entirely concealed. *Elytra* narrowly ovate in ♂, broader in ♀, narrowed at the base, which is subtruncate and not marginate, jointly rounded at the apex, with 10 regular punctate striae. *Sternum* with the gular margin shallowly sinuate and very close to the front coxae, which are remote from the base, the centro-sternal piece behind the coxae not tuberculate; mesosternum very short, so that the middle coxae nearly touch the base of the prosternum, the mesepimera reaching the base of the elytra; metasternum much shorter than a middle coxa and with no transverse fold in front of the hind coxae, the metepisterna very narrow, with the adjoining suture complete; the hind coxae not reaching the elytra. *Legs* with the front femora somewhat thicker than the others and obtusely subangulate on the lower edge; front tibiae with a sharp triangular tooth on the lower edge at a little beyond the middle, hind tibiae with the corbels open, bare and not ascending the dorsal edge; hind tarsi with joint 1 twice as long as broad, nearly as long as 2+3, 1 and 2 sparsely squamose above, 3 broadly bilobate and spongy beneath, claws connate. *Venter* with the intercoxal process much narrower than a hind coxa, rounded; ventrite 2 in the middle longer than 3+4, separated from 1 by a sinuate suture.

Genotype: *Scolochirus armipes*, sp. n.

In Dr. F. van Emden's classification of the BRACHYDERINAE this genus falls within the tribe BRACHYDERINI (Stett. ent. Ztg., **97,** 1936, p. 94) somewhere near *Sciaphobus*, but from this and allied genera it may be distinguished by its very different facies due to the marked narrowing of the elytra at their base, by the flat eyes, and by the tooth on the front tibiae.

Scolochirus armipes, sp. n. (fig. 2).

♂♀. Derm black, with dense grey scaling above and below; in the ♂ the colour is usually uniform, but in some examples there is a brownish suffusion on the disk of the pronotum and elytra; in the ♀ the brown scales tend to form a pattern on the elytra, there being a common transverse oblong patch at the base extending to stria 3 or 4, and an elongate spot at the middle of intervals 3 and 5; scales in the middle of the metasternum and basal ventrites usually pale metallic green.

Head, when the scaling is intact, appearing smooth with a fine median stria, but when abraded, the frons and the area immediately behind it are smooth and almost impunctate with a deep median sulcus extending right up the vertex, the lateral areas being finely granulate with a small elongate fovea adjoining the median area; frons shallowly concave, as wide as the dorsal area of the rostrum. *Rostrum* as long as broad, parallel-sided; the dorsal area bounded laterally by a sharply angulate margin, the lateral area being almost vertical, the basal half of the dorsum like the frons, with a continuation of the median sulcus and dense scaling, the apical half with sparse small round coppery scales. *Antennae* with the scape squamose at the apex only; funicle with joint 1 slightly longer than 2, the rest moniliform, 7 transverse and wider. *Prothorax* nearly as long as broad, rounded laterally, widest at middle, constricted before the marginate base, but not at apex, the basal angles projecting ; dorsum longitudinally convex, highest at middle, closely set with rather large granules, which are completely covered with rosette-like scaling, each granule bearing a short stiff erect seta. *Elytra* of ♂ narrowly ovate, the greatest width (at the middle) being not very much more than that of the prothorax (7 : 6), much wider in ♀, so that the unusual narrowing at the base is more pronounced (the whole insect having almost the outline of an hour-glass) ; the dorsal outline moderately convex, highest at the middle ; the shallow striae containing large close punctures which on the disk are almost concealed by scaling, the oblong scales more or less radiating from the middle of the puncture ; the intervals very narrow, hardly wider than the septa between the punctures, and somewhat sinuous, the dorsal intervals with a row of short erect spatulate setae. *Legs* with dense scaling, usually with a dark median patch on the femora ; front tibiae finely denticulate on the lower edge between the large tooth and the apex.

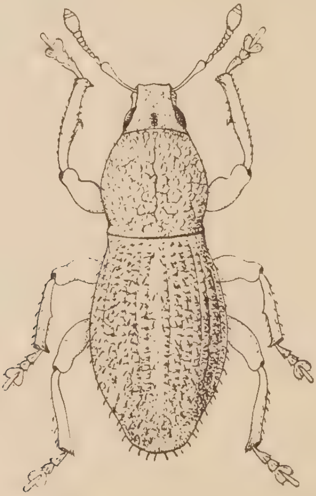

Fig. 2. *Scolochirus* (gen. n.) *armipes*, Mshl., sp. n.

Length, 4–5 mm., breadth 1·7–2·1 mm.

IVORY COAST : Bingerville, 14♂ 4♀, attacking leaves of cacao, ii.1943 (*H. Alibert*). Kindly transmitted by Dr. J. Risbec, Bambey, Senegal.

Subfamily OTIORRHYNCHINAE.

Chelyophyes, gen. nov.

General form round and extremely convex. *Head* held vertically downwards so as to be hardly visible from above, immersed in the prothorax, separated from the rostrum by a curved stria ; eyes almost flat. *Rostrum* stout, parallel-sided ; the dorsal area at its base slightly wider than the frons, the lateral areas almost vertical, so that only the apex of the scrobes is visible from above ; epistome small, almost semicircular, remote from the scrobes, with a carinate margin and a bare area behind it ; scrobes broad, deep, parallel-sided, slightly oblique but running right up to the eyes ; mentum resting on a short peduncle, with two setae. *Antennae* squamose throughout ; scape just reaching the hind margin of the eye ; funicle with joint 1 longer than 2, the distal joints transverse ; club short, broadly ovate. *Prothorax* extremely short, more than three times as broad as long, very declivous anteriorly, the apical margin vertically truncate laterally. *Scutellum* entirely concealed. *Elytra* globose, but little longer than their greatest width, extremely convex, jointly rounded at apex, sinuate at base, strongly inflexed laterally, with a large post-humeral prominence on interval 9 and ten regular striae. *Legs* with the femora moderately clavate, unarmed, the hind pair nearly reaching the apex of the elytra ; tibiae almost straight, with a short sharp mucro, the corbels of the hind pair enclosed and not squamose ; tarsi short, the claws small, connate at base. *Sternum* with the prosternum very short, the gular margin subtruncate ; the mesosternal side-pieces fused ; metasternum between the coxae hardly half as long as a median coxa, the side-pieces fused. *Venter* with the intercoxal process very broadly truncate, much wider than a coxa, the three intermediate ventrites subequal.

Genotype : *Chelyophyes hemisphaericus*, sp. n.

This remarkable genus belongs to the section of the tribe EMBRITHINI which have ten regular striae on the elytra. In my key to this group (Ann. Mag. nat. Hist., (11) **9,** 1942, p. 3) it runs down to *Peritelomus*, Fst., but differs widely from the genera of the group in its abnormal structure, having more the facies of the Brachyderine genus *Omotrachelus*, Kolbe.

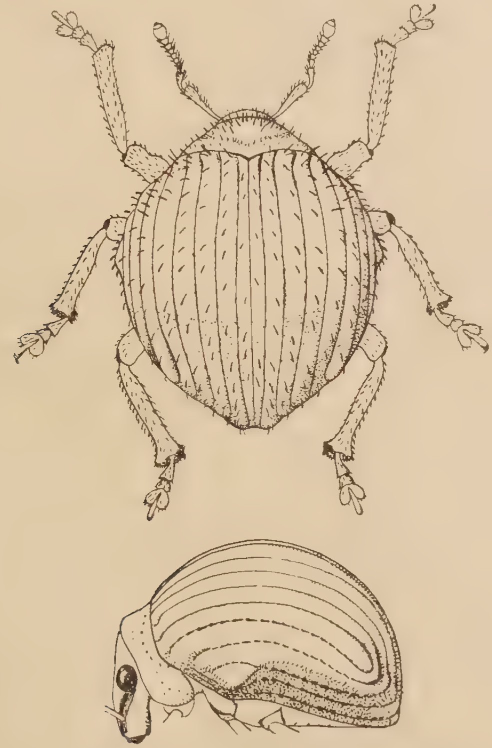

Fig. 3. *Chelyophyes* (gen. n.) *hemisphaericus*, Mshl., sp. n.

Chelyophyes hemisphaericus, sp. n. (fig. 3).

♂♀. Derm black, with dense uniform brown scaling above, becoming grey on the underside.

Head withdrawn into the prothorax, densely squamose ; frons slightly wider than the length of an eye, shallowly concave, with a short median stria. *Rostrum* somewhat longer than broad, parallel-sided ; dorsal area broad, flat, gradually narrowing from base to apex, with a fine median stria showing through the dense scaling, a row of numerous erect clavate setae along each margin and a few scattered on the disk. *Antennae* with the scape slightly curved, rapidly widening from base to apex, with dense scales and stiff erect setae ; funicle with joint 1 half as long again as 2, 3–7 subequal and transverse, 7 wider. *Prothorax* very short, strongly transverse, narrowing rapidly from base to apex with the sides straight, subtruncate at the apex, the base strongly angulate in the middle ; dorsum with a broad shallow depression across the middle and sparse deep punctures showing through the scaling, each containing a short erect seta, a double transverse row of longer setae along the front margin. *Elytra* widening rapidly from the base to one-third, where there is a large conical prominence on interval 9, the basal margin sinuate, the dorsal outline very strongly convex, almost semicircular ; the dorsal striae narrow and partly covered by scaling, the punctures showing through usually as narrow slits, but striae 8 and 9 behind the lateral prominence broad and bare, with large punctures, intervals 8–10 being here more or less sparsely squamose or even bare ; the dorsal intervals very broad, with closely contiguous fluted scales and a row of stiff erect spatulate setae. *Legs* with dense light brown scales, the femora often with darker spots ; hind tibiae with a row of very fine teeth along the lower edge, anterior pairs with only a few at the apex.

Length, 4·0–4·5 mm., breadth 3·0–3·5 mm.

IVORY COAST : Bingerville, 4♂ 3♀, attacking leaves of cacao, ii.1943 (*H. Alibert*). Kindly transmitted by Dr. J. Risbec.

Subfamily CLEONINAE.

Cosmogaster lateralis, Gyll.

Monsieur Sauvaut, Entomologist to the Experimental Station of the Union Cotonnière de l'Empire Français, at Bouaké, Ivory Coast, has forwarded specimens of this weevil with the information that the adults are injurious to cotton, as they bite off the young plants at the soil level. The species ranges from India to West Africa, but has not previously been recorded as harmful.

THE CONTROL OF SLEEPING SICKNESS IN THE RAPHIA POLE TRADE.

By T. A. M. Nash, O.B.E., D.Sc.(Lond.).

Medical Entomologist, Sleeping Sickness Service, Nigeria.

In Northern Nigeria many of the streams are choked with the Palm, *Raphia sudanica*, which affords excellent conditions for *Glossina tachinoides*. The mid-ribs of the palm fronds provide long, straight, light poles which are invaluable for roofing in a country where small straight timber is non-existent.

In areas where the palms grow to a good height, there is an important local pole-cutting industry which results in the cutters coming into close contact with tsetse. A high incidence of sleeping sickness is often associated with villages engaged in this trade. The usual solution of clearing the stream-banks of vegetation is obviously undesirable in these cases, and the following method of control has therefore been devised.

The natives are only licensed to cut the palms during the first 14 days of each quarter, *i.e.* 1st–14th of January, March, June and September. Thus, should one of the pole cutters have transmissible parasites in his blood and infect the tsetse flies at the site of the work, the parasites carried by these flies should not have reached the infective, metacyclic stage before the cutting period has closed. Since there will be an interval of at least 75 days before the next cutting period is due, all, or almost all, the individuals of that generation of tsetse will be dead and their place taken by a new, clean batch.

The writer has found that, even in the cool season, the mean longevity of *G. tachinoides*, kept in a grass hut, was under 50 days. The greatest length of life ever recorded was 93 days for males and 116 days for females. But under field conditions, where predators and lack of food may affect survival, 69 known days of male life was the greatest ever recorded from recaptured marked flies (Bull. ent. Res., **27,** 1936, p. 273). Hence it is mostly unlikely that any flies, except possibly a few that emerged at the very end of the cutting period, will survive into the next one.

This periodic system of cutting was introduced, in co-operation with the Forestry Department, in Zaria Province in January 1939, and has been accepted by the local inhabitants with a very satisfactory degree of willingness.

A LOW DENSITY OF TSETSE FLIES ASSOCIATED WITH A HIGH INCIDENCE OF SLEEPING SICKNESS.

By T. A. M. Nash, O.B.E., D.Sc.(Lond.).

Medical Entomologist, Sleeping Sickness Service, Nigeria.

In 1935, Dr. Anderson made a sleeping sickness survey of the Kudaru District of Zaria Emirate, Northern Nigeria, where he found a high incidence of the disease. In the extreme case of the small hamlet of Sambo, he recorded a 70 per cent. infection rate among the 43 inhabitants.

The writer followed up this survey with an entomological investigation in the late dry season, and paid particular attention to this hamlet.

Sambo is situated above a small stream which dries up after the rains. Exhaustive search along the stream bed for some miles on either side of the village failed to reveal the presence of a *single* tsetse or of any pools of water, but immediately below the hamlet there was a spot in the stream-bed where the sand was moist and where the villagers had scooped out a two-feet deep hole from which they obtained their meagre water supply. At this spot four *Glossina palpalis* were caught. The closeness of the man-fly contact presented ideal conditions for the spread of the disease. Each woman had to take her turn at sitting by the hole with a curved section of calabash with which she would scoop up a cupful of water and transfer it to the water pot. A pause would then be necessary to allow more water to seep into the hole. It took each woman about 15 minutes to fill her water pot. Thus for many hours each day this small tsetse population of probably less than a dozen flies could feed on the queue of women, without expending any energy in a search for food.

The case described is considered to afford a classical example of close man-fly contact. Annually, at the end of the dry season, man is forced to depend upon this one spot for his water supply. Annually, the severity of the dry season climate compels the tsetse to evacuate the other parts of the stream as the pools dry up, and to concentrate at the village water-hole where the damp sand produces conditions of lower temperature and higher humidity, and where the presence of the water-hole assures a steady food supply within the micro-climatic area.

In the writer's experience this is by no means an isolated case, but represents conditions commonly found in large areas of Northern Nigeria. When looking for tsetse in a suspected stream during the dry season, much time can be saved by asking a local guide to lead one straight to any pools of water that may still exist. Provided that shade conditions suffice, tsetse will almost invariably be found in small numbers at these places. In areas where wells are impossible or the people too lazy to dig them, or incapable of doing so, hamlets are perforce situated close to the permanent pools in the stream-beds.

High densities of *G. palpalis* or *G. tachinoides* are rarely found in the dry season, except along the main rivers in which water is much more plentiful.

STUDIES ON THE ECOLOGY OF THE LEVANT HOUSE FLY (*MUSCA DOMESTICA VICINA* MACQ.).*

By B. Feldman-Muhsam.

Breeding Methods.

Various media, natural as well as artificial, have been used by different workers for breeding *Musca domestica* in the laboratory. Kusina and Derbeneva (in Russia) reared the flies on horse manure. Lörincz (in Hungary) states that pig manure is most convenient. Kobayashi (in Korea) bred flies on a by-product of soya-beans, Hase reared them on coffee grounds, and Richardson on an artificial medium composed of a mixture of alfalfa, wheat-bran, malt, yeast suspension, and water. Some of these media and a few others (*e.g.*, white cheese) were compared. All tests were carried out at a temperature of 27°C. Females for supplying eggs were caught out of doors and kept in cages until oviposition. Fifty eggs were used in every test breeding. The results are shown in Table I.

TABLE I.

Results of breeding on various media.

	Richardson's medium	Coffee grounds	White cheese	Cow manure
Duration of development from egg to imago (in days)	12–15	—	12–15	9–13
Average number of adults bred from 50 eggs	23 ±5	Few	22·4 ±4	42·2 ±1·3
Remarks	Normal	Abnormal	Normal	Normal

It is thus evident that the best results are obtained by breeding flies in cow dung, and this medium was used in all experiments mentioned in the present paper.

Conditions for Pupation.

It is generally believed that the conditions under which the larvae develop are not suitable for pupation and that there is consequently a migration of larvae to cooler and drier surroundings preparatory to pupation. This point was studied in a field near stables in Kiryat Anavim, a hill settlement near Jerusalem, situated on rocky ground. No evidence was seen of migration prior to pupation and numerous pupae were found near the surface of dung, which during the winter months was kept moistened by cows' urine and rain. During the summer this upper layer forms a crust that is drier and more compact than the succeeding lower layers. Pupae were found in this site at temperatures of 10°–23°C. in winter and of 21°–50°C. in summer. In laboratory breeding experiments, no evidence was found of migration prior to pupation; only in cases where the dung was flooded did the larvae attempt to escape to drier surroundings.

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* This work was carried out at the Entomological Department of the Hebrew University, Jerusalem, and I wish here to express my gratitude to Prof. F. S. Bodenheimer and to Dr. O. Theodor for their valuable assistance and advice.

Relative Numbers of the Sexes.

In laboratory experiments, the number of males and females which emerge are equal but the relative proportion between the sexes varied throughout the year in one of the localities investigated. Between August 1939 and July 1940 flies were caught near the University animal house during the summer months and in the animal house during the winter months. During the summer males preponderated (in August 70 per cent. of all the flies caught were of this sex) while in winter they were relatively scarce. The proportion of females is highest in January and February, and the sexes are approximately equal in number in April and in November. The following diagram (fig. 1) shows the numerical ratio between the sexes during the year.

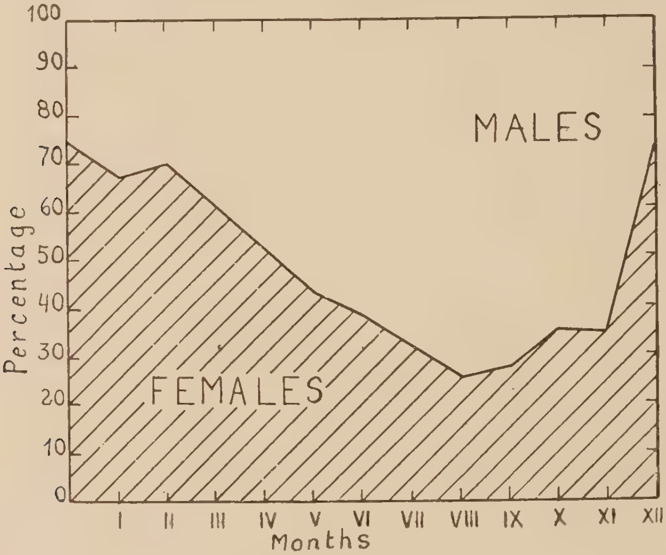

Fig. 1. The numerical ratio between the sexes of *M. vicina* during the year.

No general conclusion can be drawn from the findings in a single limited locality, and this problem requires further investigation, but it is of interest to note that in July 1941 flies caught on a manure heap near cowsheds in Kiryat Anavim also showed a preponderance of males (245 : 105).

Relation between Duration of Development and Temperature.

The duration of the individual developmental stages (egg, larva, pupa and preoviposition period) was investigated at three different temperatures: 17·5°C., 29°C. and 34°C. The two characteristic constants (the thermal constant and the zero of development) were determined for each stage from the experimental data. The data obtained at the three different temperatures satisfy the equilateral hyperbola, the equation of which is: $t\ (T-c)=\text{Th.C.}$, where $(T-c)$ equals the effective temperature, *i.e.* the external temperature T minus the threshold of development c, and t is the duration of development measured in days or hours; and Th.C. is termed the thermal constant and measured in degree-days or degree-hours respectively.

By adding together the length of the developmental periods at the different stages, the total period required for a complete cycle is obtained, *i.e.* the time elapsing from oviposition by a female until the first oviposition by its offspring.

TABLE II.

The relation of development to temperature.

	17·5°C.	29°C.	34°C.	Zero of development	Thermal constant
Egg	31·8 hours	10·75 hours	8·25 hours	12·6°C.	7·4 degree-hrs.
Larva	14·25 days	6·25 days	5·1 days	8·0°C.	132 degree-days
Pupa	13·25 ,,	5·0 ,,	3·8 ,,	11·3°C.	87 ,,
Pre-oviposition period	10·07 ,,	3·0 ,,	2·2 ,,	14·0°C.	45 ,,
Generation (egg to egg)	38·9 ,,	14·7 ,,	11·4 ,,	11·0°C.	263 ,,

During these experiments with *M. domestica vicina*, individual differences were observed in the duration of development similar to those known from observations on *Drosophila* (Bonnier) and *Lucilia* (Cousin). These differences were rather insignificant so far as the eggs were concerned, but were quite appreciable in the case of larvae and pupae. Larvae belonging to the same batch of eggs all hatched within a quarter of an hour, but differences of between one and one-and-a-half hours were observed in the times of hatching of larvae from different batches of eggs. Some larvae pupated 24 hours before the majority, while in others pupation was delayed by a similar length of time ; the majority, however, pupated almost simultaneously. Differences in the emergence of flies from pupae are of the same order.

Longevity under various Conditions.

The flies used in this experiment were reared under standard conditions at 30°C. from females taken out of doors. Flies not more than 24 hours of age were introduced into cages of tulle cloth stretched taut over a framework of iron wire. Each cage was placed in a closed glass jar containing 750 cc. of various concentrations of H_2SO_4 to maintain the required relative humidity. The temperature was kept constant during the whole course of the experiment by keeping the jars in thermostats. Cylindrical cages were used, their diameter being 12 cm. and height 14 cm. About 100 flies (50 males and 50 females) were introduced into each cage. They were fed daily on diluted milk contained in a small Petri dish,* the bottom of which was padded with cotton wool in order to prevent the flies from drowning in the milk. Special care had to be taken to feed the flies neither too much nor too little ; they are liable to drink to excess, which may cause their death, the abdomen becoming swollen and distended ; or they may suffer from starvation. The number of flies dying each day was recorded, and the data compiled in life tables.

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* It must be emphasised that the introduction of milk into the jar altered the humidity slightly, but this was inevitable. Milk is the most suitable food and is necessary since the insects die within one or two days if no nutrition is provided. Experiments on starvation furnished the following results. If flies are kept for one day at room temperature without food, 12 per cent. of the females and 62 per cent. of the males die ; after one additional day without food another 16 per cent. of the females and 27 per cent. of the males die. Almost all the surviving flies die on the third day of starvation, though some may survive up to the fourth day under optimum conditions of temperature and humidity. In order to minimise the inevitable error in relative humidity, the same quantity of milk was always introduced into the separate jars.

Results.

Under different experimental conditions the longevity of *M. domestica vicina* varies within wide limits. On the average the flies live 20 to 30 days. In certain experiments, however, they could be kept alive for 78 days at 19°C. and a relative humidity of 40 per cent. and even for 106 days at 14·5°C. and a relative humidity of 73 per cent. Hewitt in his book " The House Fly " complains of the difficulties of keeping flies in captivity and arrives at seven weeks as the maximum longevity. Kobayashi, however, succeeded in keeping flies in captivity up to 163 days. No significant difference between the longevity of the two sexes has been observed.

Although several of these experiments were carried out at the end of the summer, when under natural conditions flies are known to die of *Empusa muscae,* no cases of death from this cause were observed in the experiments recorded.

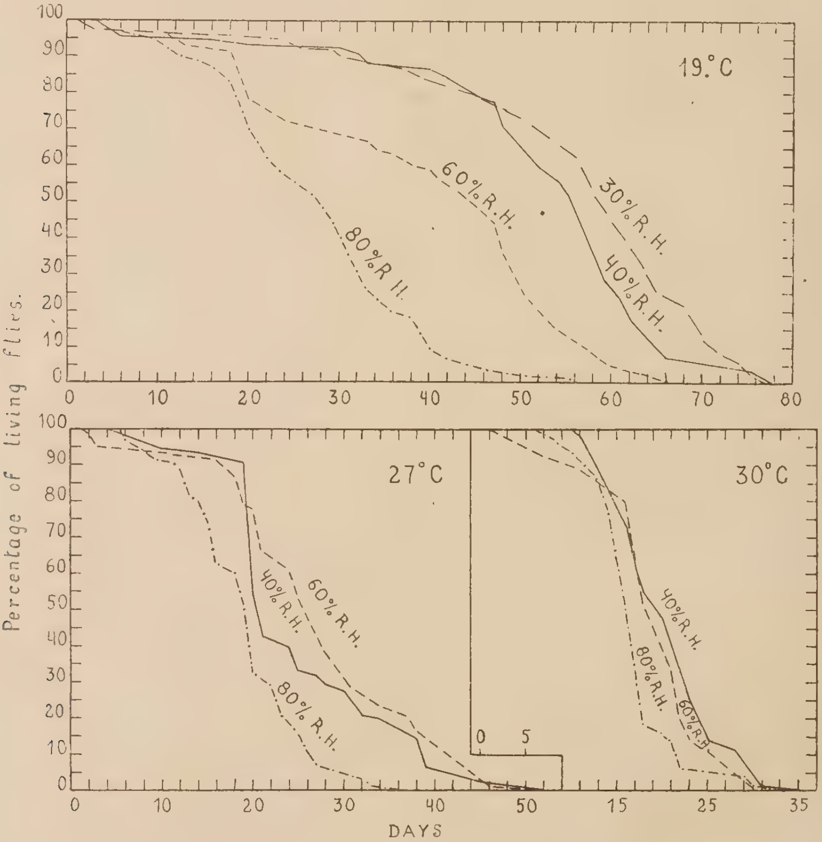

Fig. 2. Length of life at 19°, 27° and 30°C.

As may be seen from the graphs (fig. 2) during a fairly long period, depending on the temperature, only a few flies die at the beginning of the experiment, *i.e.* 10 to 30 days ; following this, the great bulk (about 80 per cent.) die within a relatively short period of time (10 to 35 days) ; finally the last remaining flies die one by one, although some of them may occasionally survive the others by a considerable length of time.

TABLE III.

The length of life of the house fly under various conditions of temperature and humidity.

Temperature in °C.	Length of life	Relative humidity				
		30%	40%	60%	73%	80%
14·5	mean				47 ±14·4	
	extreme				106	
19	mean	56 ±1·9	52·4 ±1·7	39 ±1·8		28 ±0·95
	extreme	77	78	66		57
24	mean			27·4 ±1·8	29·3 ±2	19·5 ±1·06
	extreme			46	49	31
27 Series A	mean		19·5 ±0·7	23 ±1·3		19·5 ±0·8
	extreme		37	47		31
27 Series B	mean		25·3 ±1	27 ±1·5		19·5 ±0·65
	extreme		52	52		36
30	mean		20·3 ±0·67	18·9 ±0·9		17·1 ±0·54
	extreme		36	31		34
35	mean			17·6 ±0·85		
	extreme			28		

The experiments show (Table III and fig. 2) that the influence of temperature on the longevity of the flies is, in general, greater than that of humidity. As the temperature rises, longevity decreases, but at high degrees of humidity this effect of the temperature is far less striking than it is at lower humidity. For example, at a relative humidity of 40 per cent., a change in temperature of 11°C. lengthens the life of the flies by 150 per cent. (from 20 days at 30°C. to 50 days at 19°C.), while at a relative humidity of 80 per cent., the same change in the temperature increases the longevity by only 50 per cent. (from 17 days at 30°C. to about 25 days at 19°C.). At low temperatures the life of the flies is prolonged by arid conditions, while at higher temperatures it is shortened. (A moderate humidity—40 to 60 per cent. R.H.—is always more favourable to the flies.) This phenomenon is striking at extreme conditions of heat and dryness (above 30°C. and below 40 per cent. R.H.) and is probably caused by desiccation. Under these conditions the fly is no longer able to keep the transpiration processes of the body under effective control. In dry cold (19°C. and 30–40 per cent. R.H.) living conditions are favourable and the flies are active, healthy and relatively long-lived (about 55 days). In humid cold (19°C. and 80 per cent. R.H.), on the contrary the flies are sluggish, feeble and inactive and do not live long (up to 25 days). This is probably due to the effect of the high humidity, which results in the condensation of water upon the body of the fly, whose wings are thus moistened and adhere to the body so that flight is impeded. At higher temperatures and the same degree of humidity (80 per cent. R.H.) life is short (18–20 days). For every temperature there is an optimum humidity.

The length of adult life may also be expressed as a function of the temperature by a hyperbola in which, at 60 per cent. R.H., the constants are c=7·7°C. and Th.C.= 442 degree-days.

At medium and high temperatures, an optimal humidity exists in respect of the length of life, *i.e.* at about 25°C. and higher, the life of the flies is longest at medium humidity levels, and it is shorter both at higher and lower degrees of humidity. A series of experiments at 27°C. produced the following data for adult longevity at various degrees of relative humidity : at 40 per cent.—25·3 days ; at 60 per cent.—27 days ; at 80 per cent.—19·5 days.

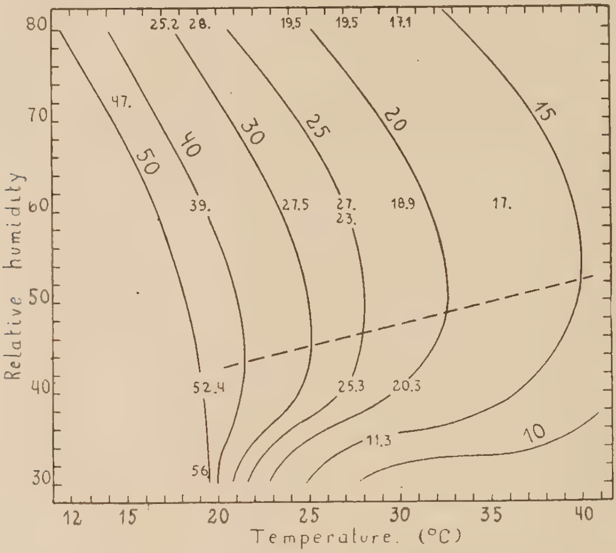

Fig. 3. The length of life as a function of the temperature and humidity. The curves connect points which mark various combinations of temperature and humidity at all of which the length of life is equal to the large number indicated alongside the curve. The smaller numbers show the length of life determined experimentally at the point at which they are plotted. The broken line connects the optimum humidity at various temperatures.

The influence of temperature and humidity on the length of life of the flies within the whole range of temperature and humidity investigated is summarised in the temperature-humidity diagram (fig. 3). In this diagram, a curve of optimal humidity may be drawn, connecting the points of optimal humidity at every temperature. This curve remains within the limits of 42 per cent. and 55 per cent. of relative humidity. As temperature decreases, lower humidity is favourable to the flies and the curve of optimum therefore descends from right to left. At a temperature below 20°C., within the range of the relative humidities studied (30 per cent.–80 per cent.) the lower are most conducive to longevity. This may also be observed in the life table curves at 19°C.

Fertility.

The large number of flies and specially the huge quantities of larvae that are found during summer in manure heaps raises the question of how many eggs a female is able to lay at a single oviposition and during its lifetime. There is scant information on this subject beyond the bare statement that the number of eggs laid at one oviposition is 120, but the fundamental question of how many eggs a female actually deposits during its whole life-time has not been sufficiently investigated. For this purpose single pairs of flies were introduced one day after hatching into glass jars and placed in a thermostat at 27°C. They were fed with diluted milk, given in a small Petri dish, the bottom of which was padded with cotton to absorb the milk. In order to make the eggs more easily visible, the milk used in this experiment was coloured with a little fuchsin.

Results of Experiments.

(*a*) *Number of eggs per batch* (fig. 4, A).

The females deposited their eggs in batches varying in numbers up to 250, but the majority of them contained 100–120 eggs. In addition a considerable number of very small batches containing only 5–10 eggs each were observed, and occasionally a female deposited a single egg. (Such cases have been left out in calculating means in paragraphs *a* and *b*.) The mean number of eggs per batch is 96·3, but the mode is 125.

(*b*) *Number of batches per female* (fig. 4, B).

The mean number of batches deposited by a female during its lifetime is 2·6, but most females deposit only one or two. The largest number observed was 9. On several occasions a female was observed to deposit 2 or 3 in one day. It is not clear in such cases whether an actual interruption of oviposition has occurred and each of these small heaps of eggs is therefore to be considered as a separate batch, or whether the female was disturbed during oviposition, in which case the individual heaps must be considered together as one batch. This second interpretation has been accepted in the present calculations.

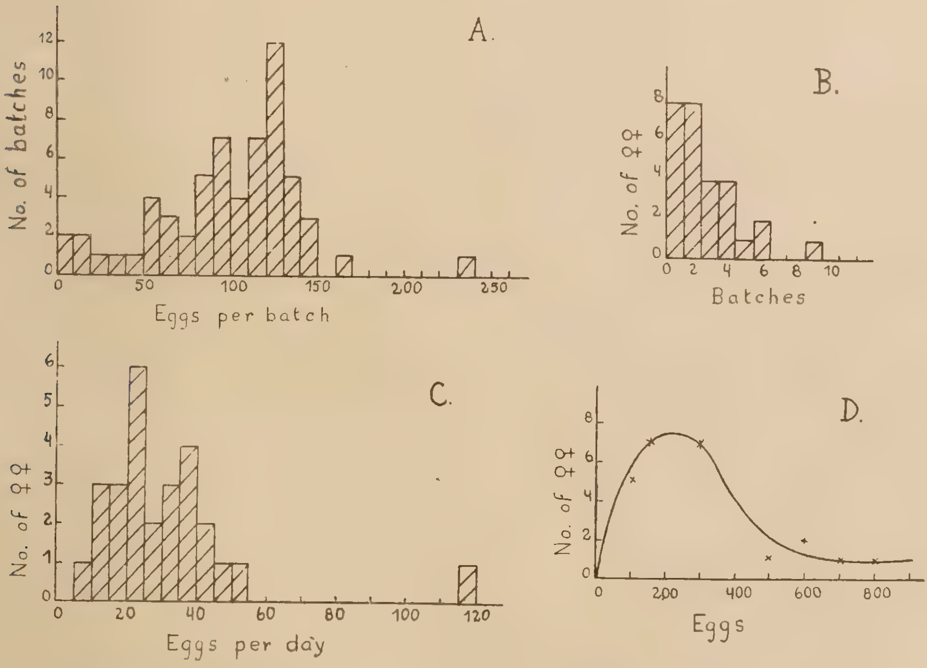

Fig. 4. A. The number of eggs per batch. B. The number of batches per female. C. The number of eggs per female per day of adult life. D. The total number of eggs per female.

(*c*) *Frequency of oviposition.*

Individual differences in the frequency of oviposition are very great. Females have been observed that daily deposit one batch of eggs, but in other cases the time elapsing between one oviposition and another is considerably greater. On the average females oviposit every 3·6 days.

(*d*) *Number of eggs per day* (fig. 4, C).

The number of eggs per day of adult life is obtained by dividing the number of eggs deposited by the number of days the female lives as an adult, no account being taken of the pre-oviposition period. On the average the female lays 30·6 eggs per day of adult life. There seems to be no correlation between the length of adult life and the number of eggs laid per day. A large oviposition by no means shortens the life of a female. On the other hand, scanty oviposition neither preserves the vitality of a female nor lengthens its life. It should be noted, however, that the three females whose adult lives were longest deposited less eggs than the mean observed per day of adult life, and in the two cases in which the largest number of eggs were laid per day of adult life, the flies lived respectively only 2 and 5 days after oviposition had begun. The experiments considered *in toto* do not show that oviposition affects longevity.

Analysis of the fertility at different ages shows that oviposition lasts until the end of life and that the rate decreases but very little and only slowly. Oviposition starts at the 4th day after emergence, and the daily rate reaches a first maximum at the 7th day, with an average of about 26 eggs per living female. Afterwards it drops and after another 6 days reaches a second peak with about 28 eggs per female. Even on the 25th–30th day the rate remains above 20 eggs per day.

(*e*) *Number of eggs per female* (fig. 4, D).

The mean number of eggs laid by a female was 267, but it must be emphasised that in this experiment the length of life was shorter than it should have been at the given temperature. The mean length of life was here 15·5 days, while that found in a special investigation on the length of life was 21 days at the same temperature and a relative humidity of 60 per cent. The reason for this discrepancy is probably to be found in the conditions of isolation of the flies in the present experiments. Density of population may have influenced the results, for according to Pearl's classical experiments, there is an optimal density of population, at which life is longest.

The females generally begin to oviposit on the 7th day of their life, but precocious females may start on the 4th day, while others commence to oviposit only on the 13th day. No post-oviposition period has been observed, and, in general, the longer the life of a female the more eggs it lays.

Although it might seem that the mean number of eggs (only 267) laid by a female is rather small (several females laid 600–700 eggs)*, the data here obtained furnish exact information as to actual conditions of fecundity. Only the number of eggs laid per day of adult life, or the frequency of oviposition and the mean number of eggs per batch, can reasonably serve as a basis for estimating the fertility of the fly. From these data it may be concluded that a fly living 21 days, of which six belong to the pre-oviposition period, lays up to 500 eggs during its life.

Hibernation.

An attempt was also made to investigate the conditions under which the house fly hibernates in Palestine. By the term " hibernation " is meant a winter sleep that may be terminated under the influence of external factors, while " diapause " is a condition of torpor due to internal factors and is not affected by changes in environmental conditions and ceases only when its due course is run. In temperate climates the development of the flies is discontinued during the winter. The flies disappear and reappear only in the summer. This fact raises the problem of the origin of the flies in the summer, the stage and location of the flies in the winter, and thirdly, whether their winter sleep is in the nature of a hibernation or a diapause.

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* L. H. Dunn (Panama) obtained 2,387 eggs from one female ; but such a number is quite extraordinary (even in the light of Dunn's own data), and it is very improbable that so many eggs can be laid during the summer months, when the life of the flies is rather short.

It can easily be proved that no diapause occurs in *M. domestica vicina* in the imaginal stage. Female flies caught in the winter months will oviposit after one day when introduced into a thermostat at 27°–30°C. Hibernating females are fertilised and carry fully-developed eggs ready for oviposition. There is evidently a definite factor that prevents them from ovipositing, a point to which reference will be made later. It has been proved on the basis of a fairly large number of rearing experiments carried out during all seasons of the year, including winter, at a temperature of 27°–30°C. under optimal conditions, that there is no diapause at any stage of development or on various media (dung, cheese and Richardson's medium). The development of the larva lasts from five to six days and that of the pupa approximately the same time. But in a few breedings, which at first glance do not differ from the others, there may be found even on the 16th–18th day after oviposition a certain number of living pupae and, more rarely, even larvae that have not yet pupated. A varying number of these pupae die, but the others continue hatching up to the 24th day.

In a number of rearings, all the larvae remained small and inactive and failed to pupate. Their state of torpor resembled that of diapause, but the real reason for its occurrence was the unfavourable conditions prevailing. In these rearing jars the dung was insufficiently fresh, and after a few days it crumbled and became rather dry. In one rearing jar, where conditions remained unchanged, larvae remained as such for a fortnight or more, and one living larva could still be found on the 25th day. Larvae which had been kept under identical conditions and behaved similarly were transferred after 12 days into fresh dung. As a result they became active, commenced feeding and pupated after four days. The stage of pupa lasted, as is normal, five days. Out of 60 larvae which were transferred in this experiment, 43 pupated, and 22 flies emerged from these pupae ; only 17 larvae died. These results are in full accord with those obtained by Cousin, working with *Lucilia sericata*. Cousin states that under favourable conditions there is no diapause, and only under unfavourable conditions of humidity, temperature or food may the development be retarded. This, however, is followed by normal development when conditions are changed.

Furthermore, four series of rearing experiments were carried out during the winter months (November-December) both out of doors and inside the laboratory. In spite of the low temperature, winds and rains, development continued during the whole of the experiments, but was very slow. In an unheated room (mean temperature during the experiment 17·5°C.) the duration of the various developmental stages was : egg, 3–4 days ; larva, 6–8 days ; pupa, 6–10 days. Out of doors (mean temperature during the experiment 12·35°C.) the development was appreciably slower : egg, 4–5 days ; larva, 17–18 days ; pupa, 13–20 days. Mortality was very high in all these experiments, but although development was very slow, no case of diapause was noted.

Various observations have given rise to different theories concerning the stage of development in which the house fly hibernates. Tishchenko supposes the egg to be the stage of hibernation, Petrishcheva the larva, and Derbeneva and Howard the pupa. All these theories, however, are based on single and incidental observations, and most investigations favour the view that the fly hibernates as an imago, and becomes active under favourable conditions of temperature.

In Palestine, winter temperatures are not low enough to interrupt the development of the flies, and their development and reproduction continue throughout the year, including the winter. Inspection of the breeding places of the flies, *i.e.* manure heaps, carried out during the winter, made it clear that an uninterrupted, although retarded, development of the flies continues not only in the valleys and the coastal plain, where the temperature is high, but also in the hill regions, for example at Kiryat Anavim, at an altitude some 1,800 feet above sea level.

It was necessary, however, to enquire into the possibility of sufficiently intense cold retarding or preventing the development of *M. domestica vicina*, and also to determine the stage most sensitive to cold and the critical temperature. In order to obtain the necessary data, the effect of the cold was investigated along two lines: (*a*) the threshold of development, (*b*) the lethal temperature.

The simplest way of determining the threshold of development is by calculating the formula of the hyperbola, expressing the relation between duration of development and the temperature, obtained from experimental data. The values obtained are as follows :—

Developmental stage.	*Temperature.*
Egg	12·6°C.
Larva	8·0°C.
Pupa	11·3°C.
Pre-oviposition period ...	14·0°C.

The pre-oviposition period is thus seen to be the most sensitive to low temperature. In general, all eggs deposited develop into the imaginal stage, but if the temperature drops to below 14°C., the female flies fail to oviposit.

In order to complete the data required, a series of experiments on the resistance to cold of the various stages was carried out. A thermos bottle filled with a mixture of ice and salt was used as a thermostat, the salt being added in varying proportions to provide the temperatures required. The subject of the experiment (flies, pupae, larvae and eggs) was introduced into a test tube and kept within the ice-salt mixture only when the temperature within the bottle had become stable. Experiments were conducted separately for all stages in groups of 20 individuals (30 being employed in the case of the eggs). The flies used were 24–48 hours of age. Pupae were taken from 9–10-day-old cultures on cow dung, and hatching, or its absence, was recorded; these pupae were approximately three days old at the commencement of the experiment. Larvae were reared on cow dung and on Richardson's medium. Experiments on larvae of the third instar showed the number of larvae surviving and number of flies subsequently developing from them. Eggs were kept on wet cotton after exposure to cold in order to create optimal conditions of humidity for hatching.

TABLE IV.

Resistance of flies to cold.

Hours h				
24	19			
12	20	0		
6	20	0	0	
3	20	14	0	
1	20	20	6	0
T	0	−3	−7	−10°C.

The number of flies enduring an exposure of h hours to the temperature T.

TABLE V.

Resistance of pupae to cold.

Hours h					
24	20	0			
12	19	0	0		
6	19	8	0		
3	19	18	0		
1	20	20	16	0	
	0	−3	−7	−11°C.	T

The number of pupae enduring an exposure of h hours to the temperature T.

TABLE VI.

Resistance of larvae to cold.

Hours h										
48		20								
24	20	20	20				0			
12	20	20	20				0			
6	20	20	20	0						
3	20	20	20		0			0		
1	20	20	20		2	2			0	
	5	0	−4	−6	−7	−8	−9	−10	−11°C.	T

The number of larvae enduring an exposure of h hours to the temperature T.

TABLE VII.

Resistance of larvae to cold.

Hours h										
48		20								
24	18	16	13				0			
12	17	19	16				0			
6	19	19	15	0						
3	20	19	16		0			0		
1	20	20	16		1	2			0	
	5	0	−4	−6	−7	−8	−9	−10	−11°C.	T

The number of flies emerging from pupae, when larvae have been exposed to the temperature T during h hours.

TABLE VIII.

Resistance of eggs to cold.

Hours h	0	−3	−6	−8	−10	−11°C. T
24	0					
12	23					
6	27	0				
3	30	0	0	0		
1	30	27	27	20	0	0

The number of eggs enduring an exposure of h hours to the temperature T.

The results of the resistance experiments are summed up in Tables IV–VIII which show clearly the lethal temperature for each stage and the dependence of the effect of the temperature on the length of the exposure. Comparison of the tables shows that the most resistant stage is that of the larva, 100 per cent. of them withstanding a temperature of −4°C. for 24 hours, whereas none of the pupae or imagines can endure temperatures below 0°C. for the same length of time, and no egg survives such exposure. The pupae are more resistant to cold than the imagines : after exposure for six hours to −3°C., 40 per cent. of them survive, whereas imagines exposed to the same conditions all die. Although eggs are most sensitive to the effects of prolonged cold, they are more resistant than other stages to intense cold for a short period, at least 60 per cent. of them survived exposure of 1 hour to a temperature of −8°C., while only 10 per cent. of the larvae can survive these conditions. It is interesting to note that the time factor has no important effect on the resistance of larvae to the cold, and for all lengths of exposure periods from one to twenty-four hours the lethal temperature is between −5° and −7°C.

In addition to the numerical data on survival after exposure to cold for varying periods of time, certain peculiarities in the behaviour of the different stages during and after the exposure have been noted. The flies lay in the test tube during the whole time of the experiment without movement. After exposure to a temperature of 0°C. for up to 12 hours, they recovered quickly from their state of paralysis if removed to a favourable temperature. After exposure to lower temperature, the flies remained in a state of paralysis for a certain length of time after removal from the cold, beginning to move their legs slowly while lying on their backs only after 15 minutes to one hour had passed. A certain number recovered from this state and the rest died.

A comparison of the two tables (VI and VII) dealing with the resistance of larvae shows that not all larvae that survive exposure to cold for a certain length of time pupate and reach the stage of imago. After having been kept at 0°C. for up to 48 hours, almost all larvae continued their development, but after exposure to −4°C. for 24 hours, although all larvae survived, only 65–80 per cent. ultimately developed into flies, and it is therefore obvious that the latter conditions although not directly lethal induce pathological changes in some individuals. It should be pointed out, that after removal from unfavourable temperatures some larvae reacted to mechanical stimulation although they subsequently failed to develop. Motility after exposure to cold should therefore not be considered a proof of viability. After being kept for one hour at −7°C., almost all larvae reacted to excitation, but they died on the same day. After being kept for one hour at −11°C. some larvae became brown, and the others although normal in appearance, did not respond to mechanical stimulation.

In larvae exposed to low temperatures up to the very limit of their endurance, and then removed to favourable conditions, certain peculiarities are observed. Some cease development and remain at rest ; they may remain alive for a few days without moving (after exposure of 3–6 hours to —10°C.). In such cases either the flies ultimately developing from these larvae die during emergence, or a certain number of the larvae (10–50 per cent. according to conditions) pupate *abnormally*. After being exposed for 24 hours to —4°C., 35 per cent. pupate abnormally and fail to reach the imaginal stage.

In the *normal* pupation of *M. domestica vicina* two processes have to be distinguished : (*a*) the shortening and contraction of the larva ; (*b*) the pigmentation and hardening of the outer skin of the pupa. The first part of pupation, *i.e.* the transition from the shape of the larva to that of the pupa, lasts about an hour in *M. domestica vicina*. During this time, the larva contracts, shortens, rounds up gradually and finally becomes motionless, and this coincides with the termination of the third ecdysis. Immediately afterwards, the second process begins. The pupa becomes yellow and goes through a succession of colour changes, tan, red and brown. The rate of pigmentation varies with the temperature ; at 30°C. the pupa becomes red in 1½ hours, but complete pigmentation (brown) is attained only after a few hours have passed. In *abnormal* pupation it is the first process which is eliminated. The larvae fail to contract or contract only partially. Fig. 5 shows two instances of abnormal pupae that have contracted to varying degrees. In one case (A) the pupa has contracted very slightly and resembles a larva ; in the other (B) the pupa has contracted somewhat more but still incompletely, and it lacks the characteristic round shape.

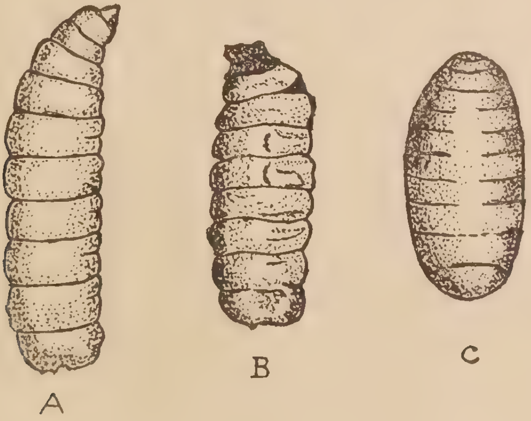

Fig. 5. A, B. Abnormal pupae ; C. Normal pupa (for comparison).

The second process, that of pigmentation and hardening was invariably present in all cases both of normal and abnormal pupation as defined above*. A single case of abnormal pupation has been observed in which the anterior part of the body alone, without previous contraction, became hardened and pigmented, the posterior part remaining yellow and rumpled in a very irregular manner. There was no instance of hatching from abnormal pupae.

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*Abnormal pupation of a different type has been observed in *Calliphora erythrocephala* ; the first stage of pupation was completed but was not succeeded by the second and the pupae died but remained white.

It is clear from the data on the resistance to cold of the different stages of *M. domestica vicina* that in Palestine development may continue throughout the year, for the temperature rarely falls below 0°C. even at night, while the temperature within the manure heaps, where development takes place, is always higher than that of the external environment. The lowest temperature observed within a manure heap was 10°C. in daytime, and there is no considerable fall in temperature during the night.

Flies kept during the winter months in a cage on a southern window ledge and exposed to wind and rain did not die. They remained inactive, and if not disturbed, rested on the ceiling of the cage. This proves that weather conditions during the winter are not fatal to the flies.

The interruption in the development of *M. domestica vicina* during the winter in Palestine cannot be due to low temperatures fatal to flies in any stage of their development, but to the high humidity of the breeding places and the inhibition of oviposition. In regard to the former, a large number of dead larvae were found in manure heaps after heavy rainfall in the winter, and pupae gathered in wet places failed to develop into imagines. It has already been mentioned that 14°C. is the threshold of oviposition. The mean winter temperature in Palestine remains below 14°C., but there are always hot days on which the temperature rises considerably above this.

In order to study more closely the phenomenon of the threshold of oviposition, fertilised females were kept out of doors during the winter months. They were kept in tulle cages in a southern window, and as long as weather remained cold, they did not oviposit. With the advent of somewhat warmer days with sufficient sunshine, however, a few ovipositions were observed. Females one day old kept at a constant temperature of 13·5°C. failed to oviposit for 65 days. It was suspected that at this temperature the ovaries failed to develop, but examination of them carried out periodically during the whole course of the experiment proved that they developed normally and that the ova reached their maximal size within 20 days. The ova then remained in the ovary of the female at this stage, but were not deposited for the 45 days and more of the experiment. When transferred to 38°C., however, these females laid their eggs within 12 hours. The threshold of oviposition as calculated from the hyperbola of the time-temperature relation is 14·0°C., and the above experiments are in satisfactory agreement with this theoretical value.

It has thus been shown that there is no diapause at any stage of the development. In the imaginal stage, however, hibernation does occur, and the preservation of the race is guaranteed by the hibernating females carrying fertilised eggs ready for oviposition.

Summary.

Cow dung was found to be suitable for breeding *M. domestica vicina*.

The dependence of the duration of development on the temperature was investigated for all stages of development and could be suitably expressed by the formula of an equilateral hyperbola.

Adult longevity was studied under various conditions of temperature and humidity. The maximum length of life in captivity was found to be 106 days, the average being 20–30 days. As the temperature rises, longevity decreases. Above 20°C., life is longest at a relative humidity of 42–55 per cent., whereas below 20°C., a lower humidity (30–40 per cent. R.H.) is favourable.

Fertility was studied from the point of view of size of individual egg hatches and the frequency of oviposition.

The mean number of eggs deposited by a female fly per day of adult life does not depend on the duration of adult life and does not change considerably during life.

At 27°C. and medium humidity, a single female lays about 500 eggs during its life-time.

No diapause occurs in *M. domestica vicina* in any stage of its development in Palestine.

The threshold of development was calculated for all stages and the lower lethal temperature was determined experimentally. Among other effects of low temperature (immediate and delayed) abnormal pupation is described.

At a temperature of below 14°C., the adult female does not oviposit although the eggs develop. Above 14°C. oviposition occurs during all seasons.

The development of larvae and pupae continues during the winter at a diminished rate.

In winter large numbers of larvae and pupae are destroyed in their breeding places, not by the low prevailing temperatures, but by excessive humidity.

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THE SUGAR-CANE SCALE, *AULACASPIS TEGALENSIS*, ZEHNT.

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(PLATE I.)

Introduction.

The sugar-cane scale, *Aulacaspis tegalensis*, Zehnt., has been known to exist in Mauritius since the year 1899, when de Charmoy recorded it for the first time in the Island.

The species was described by Zehntner in 1898 from Java on sugar-cane, since when little has been recorded of its geographical distribution. In 1921, Ferris recorded it from Formosa. In 1938, D. d'Emmerez de Charmoy, jr., called the attention of the planters of Réunion to the damage caused by this scale on sugar-cane, and the author had suspected its presence there many years previously. In Java it was considered of minor importance by Zehntner in 1897. In 1911 Van Deventer drew attention to the damage it caused in Java, and in 1915 van der Goot recorded a serious infestation in the experimental cane fields of the Java Experimental Station. Apart from these records, it has not been reported from other sugar-cane growing countries.

Since 1899, *A. tegalensis* has occasionally been reported as causing some injury to sugar-cane plantations in Mauritius. These records relate to the years 1914, 1929, and 1937, and it appears therefore that its dispersion in the Island has been very slow, and that environmental conditions have not always been favourable to its spread. The previously reported attacks were originally sporadic ones, and the infested areas of cane fields varied between five and ten acres; these were scattered mostly in the coastal belt of the Island.

Since 1937, the scale has spread in numerous small foci of infestation nearly all over the western coastal belt of the Island over an approximate area of 4,522 acres under cane cultivation. On some estates, these foci of infestation have spread over patches of cane fields as large as 25 acres, which subsequently were completely attacked. There appears no doubt that its increase during the last five to six years has been due to some environmental factors that were not present some fifteen years ago. The yearly steady increase may in future give rise to alarming conditions. The present study is, therefore, intended to throw some light on the actual status of this pest, with a view to advocating some measures of control that might help to check it whilst it is still not yet a threat to the whole of the sugar industry of the Island.

Economic Losses.

The damage caused to sugar-cane plants is twofold, a reduction in yield and a reduction in sugar content. From information gathered on various heavily infested estates, the reduction in tons per acre ranges between 5 to 15 tons of canes. In order to obtain some accurate figures of the loss in sucrose content, the brix of the juices of healthy and infested cane stalks were determined with the hand refractometer.

A field of P.O.J. 2878 was selected for this purpose. As it was practically impossible to obtain completely healthy canes in the field, it was decided to consider as healthy those canes upon which only very few insects were found. The samples were divided into three lots: (*a*) heavily infested canes, (*b*) moderately infested, and (*c*) healthy canes. Twenty-five canes were selected at random in each category ; top, middle, and bottom samples of juice were taken from each cane and the brix of the juice determined. To eliminate the difference in brix due to soil variability, the cane stalks were chosen from stools not far apart from each other. The figures given below were kindly analysed statistically by Mr. A. de Sornay, cane breeder of the Sugar Cane Research Station, Reduit, with the following results :—

TABLE I.

Nature of sample	Brix			
	Top	Middle	Bottom	Mean
Healthy canes	12·95 ±0·23	16·67 ±0·20	18·47 ±0·17	16·02 ±0·17
Moderately infested canes	11·39 ±0·43	15·37 ±0·52	17·50 ±0·33	14·47 ±0·35
Heavily infested canes ...	9·30 ±0·43	9·56 ±0·52	12·15 ±0·55	10·34 ±0·41

The differences between the brix of top, middle, and bottom samples were found statistically significant as well as the differences between the mean brix. Table II recapitulates the analysis :—

TABLE II.

Difference between the mean brix of :		Significance
Healthy and moderately infested canes	1·28 ±0·39	Significant
Moderately and heavily infested canes	4·40 ±0·52	Highly significant
Healthy and heavily infested canes	5·68 ±0·44	Highly significant

The above determinations were made at the beginning of May 1942, and no doubt the differences would have been higher if samples were taken at the beginning of the crop season in August, when the cane plants are fully ripened. Owing to other war duties, a second determination of the brix was not possible in August. Results from the above table show that difference between the mean brix of healthy and heavily infested canes is 5·68±0·44 ; this difference is equivalent to a drop of about 35 per cent. in the brix of healthy canes. From other figures obtained in 1941, the mean percentage of sugar lost in the cane was 21·2.

The varieties reported to be infested are the following : P.O.J. 2878 ; B.H. 10/12 ; M 134/32 ; M 171/30 ; M 72/31 ; M 55/1182 ; M 7/23. The main severe attacks were noticed on the variety P.O.J. 2878, which appears to be the variety the most heavily attacked by the scale insect. Furthermore it was found that varieties with persistent and adherent leaf-sheaths were more severely infested than those with loose leaf-sheaths.

Morphology.

Aulacaspis tegalensis was described in 1898 by Zehntner in the genus *Chionaspis*. In 1921 Ferris assigned it to *Aulacaspis*. The following technical description of this scale is by Mr. Raymond Mamet, of the Department of Agriculture, Mauritius.

> " *Female puparium* (fig. 1, *a*) pure white, with the exuviae to one side, fairly convex, more or less circular, with its margin situated near the exuviae somewhat recessed. *Nymphal exuvium* straw coloured, more or less obscured by a white secretion. *Larval exuvium* pale yellowish, shiny, projecting beyond puparium. Average diameter of puparium, 3·04 mm.

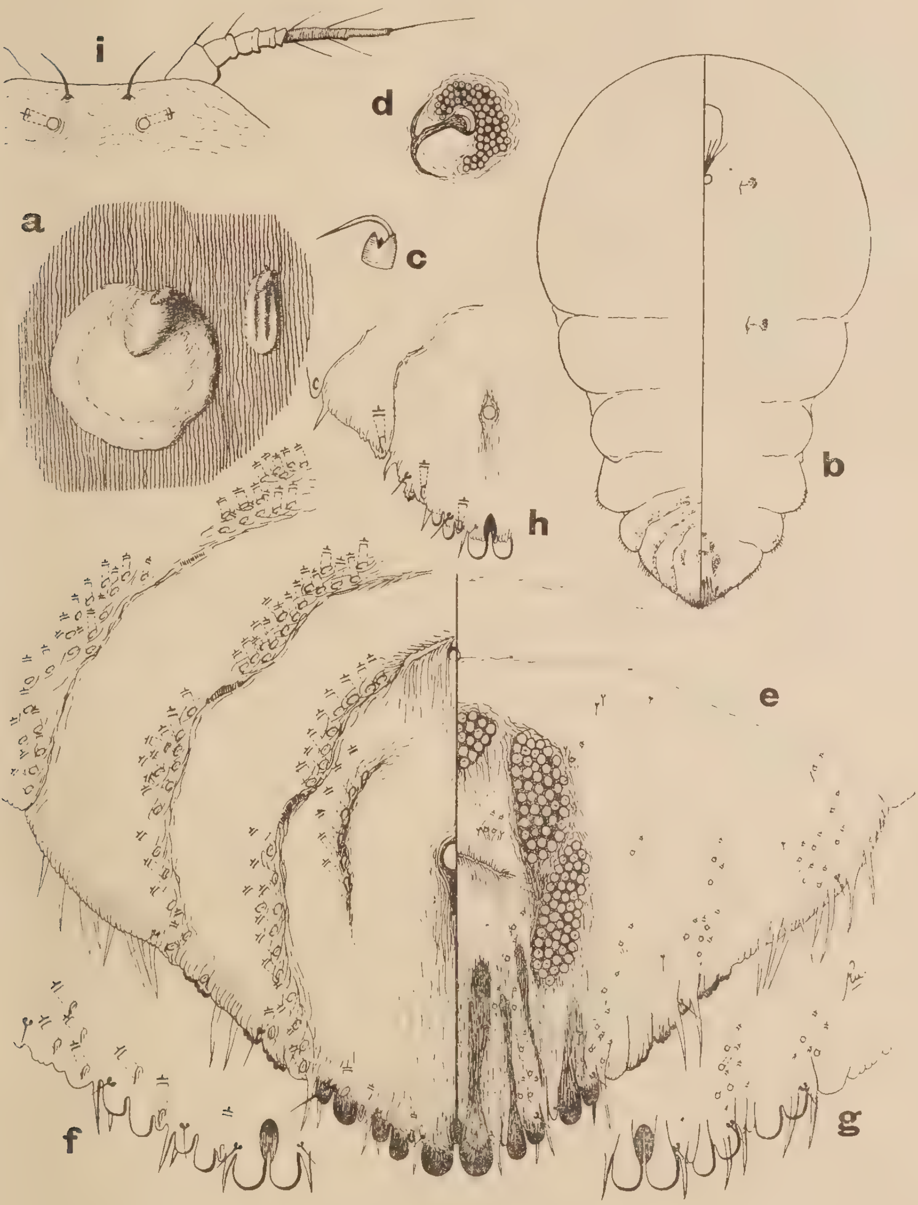

Fig. 1. *Aulacaspis tegalensis*, Zehntner: *a*, Female and male puparia; *b*, adult female; *c*, antennal tubercle; *d*, anterior spiracle; *e*, pygidium; *f*, enlarged portion of dorsal margin of pygidium; *g*, enlarged portion of ventral margin of pygidium; *h*, pygidium of female nymph; *i*, anterior portion of first stage larva.

"*Male puparium* (fig. 1, *a*) small, tricarinated, pure white in colour. *Larval exuvium* terminal, very pale yellowish in colour.

"*Adult female* (fig. 1, *b*) elongate in form. Length, 1·6–1·9 mm. *Prosoma* swollen, broadly rounded in front, exceeding remainder of body in width. *Derm* membranous except for the apex of pygidium, and, in old individuals, a number of small sclerotised areas of the prosoma, metathorax and first abdominal segment. Second abdominal segment rather more produced laterally than either the 1st or 3rd. *Antennal tubercle* (fig. 1, *c*) with one seta. Both *spiracles* (fig. 1, *d*) with a compact group of parastigmatic pores. *Dorsal ducts* (fig. 1, *e*) arranged in definite rows, composed of submarginal and submedian series, on the 3rd to 6th abdominal segments; the submarginal series extending to the 5th segment and the submedian series to the 6th segment. *Macropores* (fig. 1, *e*) present on margin of 4th to 7th segments. Few ventral *micropores* (fig. 1, *e*) with short tubular ducts present on the submarginal area of 1st to 7th abdominal segments and thoracic segments. *Squames* present on 2nd to 7th segments of abdomen. Ventral "conchiform plates" absent. *Pygidium* (fig. 1, *e*) with 3 pairs of trullae. Median *trullae* (fig. 1, *f*, *g*) zygotic at their base and very slightly divergent, without any pores or squames between them. The median sclerosis which yokes the trullae is somewhat weak, but is distinct. Second and third pairs of trullae bilobed. Five groups of *perivulvar* pores: median with 10–48, upper laterals with 36–50, and lower laterals with 29–53 pores. *Anal orifice* subcentral.

"*Nymph* oval, fairly sclerotised. Length 0·8–0·9 mm. *Pygidium* (fig. 1, *h*) with median trullae zygotic without pores or squames between them. Other trullae bilobed.

"*First stage larva* oblong, with 5-jointed antennae (fig. 1, *i*); last antennal joint longest and annulate. A pair of typical ducts on frontal area present. Length about 0·25 mm.; breadth about 0·12 mm.

"*Remarks*: The figure of the adult female published by Ferris (1921, fig. 2, A) for *A. tegalensis* from Formosa does not agree with that (fig. 1, *b*) for the same species from Mauritius. The most important differences are: The dorsal pores are present on the second abdominal segment in the Formosan insect, whereas, in specimens from Mauritius, pores on the second abdominal segment are entirely absent; in addition the 3 pairs of ventral "Conchiform plates" in the Formosan insect are absent in the Mauritian individuals.

These differences are, in my opinion, sufficient to separate these two insects into specific aggregates; whether the Formosan or the Mauritian insect represents true *A. tegalensis* can be ascertained only in the presence of either the type slides or the type material of this latter. But, owing to the present circumstances, this matter must remain unsettled.

"The present species is assigned to the genus *Aulacaspis*, Cockerell, on account of its swollen prosoma and of the presence of dorsal pores in a submedian row on the 6th abdominal segment."

Bionomics.

The life-history of the scale was worked out in the laboratory as well as in the fields. In the open air, several cane plants in different cane stools were chosen for observation; it was, therefore, possible by this method to record the succeeding generations under natural conditions. Laboratory infestation of young cane plants was tried in different ways without great success; it was finally found easier to follow the various stages by placing longitudinally-cut portions of the cane stalk in Petri dishes containing only a film of tap water to prevent desiccation. The film of water was renewed daily. Cane stems, thus artificially infested, could be kept in good condition for more than a month, thereby permitting a study of the life-cycle of the scale. The data obtained from the laboratory were corroborated with field observations.

The number of eggs laid per female varies between 150 to 250 ; the eggs are laid all round and under the posterior end of the adult female ; they are well protected by the scale covering. The egg is yellowish when first laid and becomes densely yellow at the close of the hatching period. It measures 0·25 mm. in length and 0·125 mm. in breadth, has a smooth surface and is oblong in form. The eggs hatch in about 6 to 7 days in summer, and in about 10 to 12 days in winter. The percentage of eggs hatched was 98 in summer and 83 in winter.

The small larva or crawler, on hatching, is very active and wanders on the host plant for a period of 24 to 48 hours before finding a suitable place to settle when it starts feeding. As soon as hatched, the crawler can travel on a flat smooth surface, at the rate of two metres in one hour. This activity diminishes gradually with the hours preceding fixation. An average of 60 per cent. of the crawlers generally settle themselves ; the mortality during the crawling period averages 40 per cent. The young larva is yellow in colour, and 24 hours after it has settled it starts secreting a whitish tuft of hair-like structures that extend all round the entire insect. The average dimensions of the active larva are 0·30 mm. in length and 0·13 mm. in width. On the 6th to 7th day after it has fixed itself on its host, the larva transforms into a nymph. Differentiation can then be established between nymphs to be transformed into male and female adults (fig. 1, *a*). The nymphal period for males is 10 days as a mean, and for females 13 to 14 days. The total life-cycle from egg to adult averages 24 days for males and 28 days for females, at temperatures between 24°C. and 27°C. and at a mean relative humidity of 74 per cent.

Females, before being fertilised, are pale yellowish in colour and when gravid are pinkish in colour.

The general appearance of the scale covering is white, subcircular and measures 2·51 mm. to 3·57 mm. in diameter. The scales are crusty and cover nearly the whole of the cane stalks in severe infestations (Plate I, figs. 3 and 4).

The insect is generally found on the cane stems ; but in severe infestations, leaf blades and leaf-sheaths are also attacked (Plate I, fig. 2). Larvae are generally found below the nodes of the upper part of the cane stalk and on that part of the stem still tightly enclosed by the sheaths.

Damage by this scale is generally observed from February to August, after which the infested canes are reaped. At least six generations occur during the period February to July. In ratoon fields, infestation may start as early as December on cane stalks left in fields with a view to inducing rapid growth of young shoots in cane stools ; these extra stalks are locally known as " babas." It has been noticed that cane fields adjoining infested ones generally become attacked, the dispersing agent being mainly wind. The infestation by wind propagation is not very destructive to plantations in the first year of attack ; it is in the subsequent years that severe losses are encountered, this being mainly due to permanent foci of infestations left as " babas."

Natural Enemies.

The natural enemies of *A. tegalensis* in Mauritius are *Chilocorus politus*, Muls., *C. nigritus*, Muls., *Lindorus lophanthae*, Blaisd., *Cybocephalus* sp., and parasitic Hymenoptera.

Prior to the introduction of the two species of *Chilocorus* in the years 1937 and 1939, the main predator recorded on the sugar-cane scale was *Lindorus lophanthae*, Blaisd.

Owing to lack of data it has not been possible to trace the first record of the Hymenopterous parasites on the sugar-cane scale in Mauritius. It is probable that they existed as far back as 1922, when the writer recollects having examined cane stalks infested with the scale and showing signs of having been heavily parasitised by microscopic Hymenoptera. As the scale at that time was of minor importance to sugar plantations, no special attention was devoted to it or to its various natural enemies.

The actual status of the various parasites and predators from laboratory and field observations collected from the present study can be summarised as follows.

The distribution of the various above-mentioned Coccinellids in infested centres is very uneven throughout the year. In some places, the leading predator at the beginning of the year was *Chilocorus nigritus*, whilst in other places it was *L. lophanthae*, or *C. politus*. In one infested centre, it was possible to study more closely the relative frequency of the various predators during a period of nine months. Fig. 2 shows the relative abundance of the various species during the period December 1941 to August 1942. Coccinellids are rare in the infested fields in January, this being mainly due to the lack of host material, all infested cane stalks having been reaped during the crop season ; their numbers then rise and reach a peak in July when host materials are abundant in the field. These observations were made at one infested centre in the north-west of the Island where the maximum temperature in summer was between 28° to 30°C. and the minimum 23° to 24°C., the mean relative humidity during the months under observation was 66 per cent., and the mean rainfall 55·6 mm.

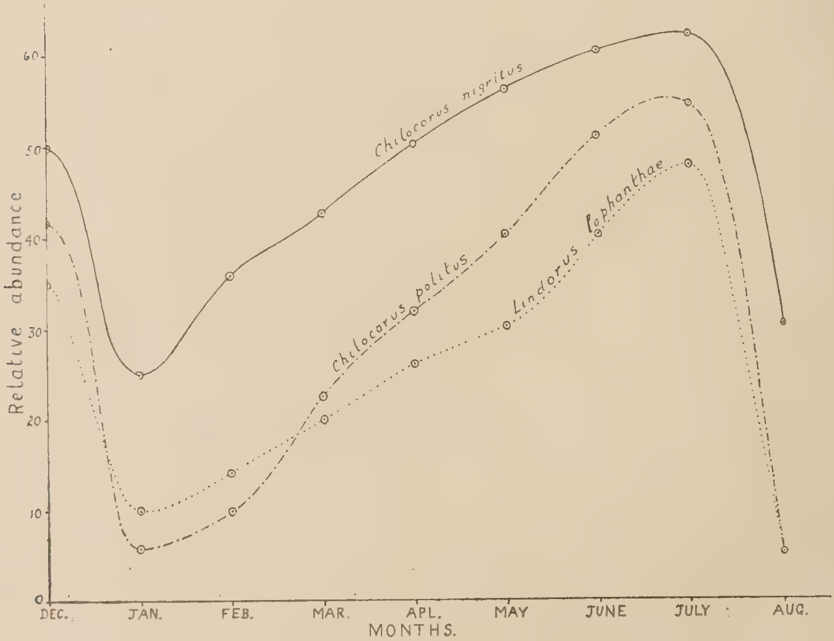

Fig. 2. Curves showing the relative abundance of Coccinellids in the scale-infested cane field under observation.

The life-cycle of the three Coccinellids was worked out in the laboratory at Reduit. (Maximum temperature during observation=28° C.,minimum temperature=21°C., relative humidity between 68 and 76 per cent.) The following table summarises the esults :—

TABLE III.

Species	Generation	Egg stage (days)	Larval stage (days)				Total larval stage	Pupal stage days	Total life-cycle (days)
			1st instar	2nd instar	3rd instar	4th instar			
C. politus ...	summer	8–9	3	3	3	4–5	13–14	5–6	27–29
,, ,, ...	winter	10–11	3	3	3	5–6	14–15	6–7	30–33
C. nigritus ...	summer	9–10	2	2	3	5–6	12–13	5–6	26–30
,, ,, ...	winter	10–11	3	3	3–4	5–6	14–15	6–7	30–34
L. lophanthae ...	summer	8	—	—	—	—	16	7	31
,, ,, ...	winter	11	—	—	—	—	17–18	8	36–37

It will be seen from the above table that the life-cycles of the two species of *Chilocorus* are nearly equal in length ; furthermore it was found that these two species rarely occur at the same time in the same abundance in many infested cane fields, the peak of one species appearing to succeed the other during the course of the year. Though the abundance of these Coccinellids was very spectacular in infested cane fields, it can hardly be said that they check the pest on the Island by themselves, because re-infestations were commonly noticed in fields previously infested and harbouring thousands of Coccinellids. The species of *Cybocephalus* was found in all infested fields during the month of March, but appeared to be a very seasonal and limited predator.

Hymenopterous parasites (*Tetrastichus* sp. and *Homalotylus* sp.) were found abundantly in infested cane fields during May and June. The incidence of their parasitism was closely linked with the abundance of host material in the field. This parasitism could be increased to a very appreciable index, if the scales were more fully exposed to the attack of the Hymenopterous parasites by the removal of trash from infested stalks. This subject is fully discussed below. The life-cycle of the two Chalcids averages 17 days. It is hoped in due course to give fuller details of their biology.

Control Measures.

In order to be able to recommend some practical measures of control, the following experiments were carried out :—

(*a*) Viability of the scale in infested planting materials or cane cuttings.

(*b*) Effect of trash removal on the increase in the population of parasites and predators.

With regard to the viability of the scale on cane cuttings, it was found that the former can breed freely on the latter when left in the field under sun exposure for a period of at least 30 days ; a new generation of the insect may take place on cuttings thus exposed in the field. On the other hand, the scale, in any stage, could not live for more than 10 to 12 days when buried in the soil ; and the wetter the soil the sooner it died. In irrigated lands it died in the soil after 6 to 8 days. As an experiment, five series of ten infested cuttings were planted at the same time when several cane plantations were made on a large scale on some infested estates in the Island ; it was found that in no case did the newly sprouted shoots show signs of attack by scales. Infestation of new plantations by planting materials coming from infested fields can therefore be considered as very remote, provided that the cuttings are planted as soon as they are received from the infested centres. From general observations, it can be stated that the local practice on some estates of keeping some extra shoots or "babas" in the field after the crop season is the main potential cause of infestation. In no case whatever should extra stalks be left in infested fields. In one field under constant observation, it was found that re-infestation occurred in all stools where "babas" have been left, whilst in all the stools where the cane stalks were cut as closely as possible to the soil level, re-infestation was nearly nil.

The experiment on the removal of trash was carried out in a heavily infested cane field. The field was divided into two parts: in one section the cane trash was removed and in the other the infested cane plants were left as a control. Two months after the trash removal, the brix of the trashed and untrashed canes were determined. The results are given in Table IV.

TABLE IV.

Nature of experiment	Brix				
	Top	Middle	Bottom	Mean	Remarks
Untrashed cane plants	11·11±0·23	14·53±0·62	16·94±0·72	14·06±0·44	Percentage of scales parasitised 2·6
Trashed cane plants	12·53±0·42	19·34±0·27	21·28±0·17	17·72±0·22	Percentage of scales parasitised 90

The difference between the mean brix was 3·66±0·48, or about 20 per cent. between trashed and untrashed canes. Moreover it was noticed that the parasitism of the scale rises from 2·6 per cent. to 90 per cent. when the trash was removed. The Coccinellids were also found more abundant in the section where the trash had been removed, thus showing that, by the trash removal, the scale insect was more exposed to the attack of its parasites and predators.

This method is therefore highly recommended in places where removal of trash is possible and where irrigation is available. Observations in the field showed that the variety P.O.J. 2878 has very adhering sheaths as compared with other varieties like B.H. 10/12 and M. 134/32. In the latter varieties, no severe infestation was recorded. In the writer's opinion, one of the main factors that has contributed to the increase of the sugar-cane scale in some parts of the Island has been the propagation of varieties, like P.O.J. 2878, which are generally heavily infested and to which parasites and predators can have but little access to check the spread of the pest. Owing to the present conditions, a survey of the varieties that possess loose leaf-sheaths could not be made. It is recommended that planters should in future seek varieties that possess loose leaf-sheaths together with all the factory and field requirements according to their localities.

Summary.

The origin, occurrence and distribution of the sugar-cane scale insect, *Aulacaspis tegalensis*, in Mauritius, are fully discussed.

Economic loss due to attack of the scale has been determined and the figures statistically analysed. A reduction of 5 to 10 tons of canes per acre was reckoned and the loss of sucrose per cent. sugar in the cane amounted to about 35 per cent.

The varieties infested by the scale are P.O.J. 2878 ; B.H. 10/12 ; M. 134/32 ; M. 171/30 ; M. 72/31 ; M. 55/1182 ; M. 7/23. Of these, P.O.J. 2878 is the most highly infested in the Island.

A description of the scale insect is given, and the bionomics have been worked out. The incidence of the pest in the Island is discussed ; infestation is at its peak during the months of February to July. The complete life-cycle averages 24 days for males and 28 days for females.

A list of the natural enemies in Mauritius is given, and *Chilocorus politus*, *C. nigritus* and *Lindorus lophanthae* were the commonest predators. Prevalence of two Hymenopterous parasites is also recorded. The bionomics of the various predators and parasites are described.

The presence of "babas," or extra cane stalks, in infested cane stools is not recommended, as these were found to be the main sources of infestation and re-infestation in the Island. The viability of the scale on cuttings is discussed. Cuttings when left exposed in the fields can harbour live insects for a period as long as 30 days, whilst the insect does not survive on cuttings after 10 days in wet soil.

Trashed cane plants showed an increase of 30 per cent. in sucrose as compared with untrashed plants. Parasitism by Hymenoptera in untrashed cane plants was 2·6 per cent. as compared with 90 per cent. in trashed canes. The beneficial effect of the removal of cane trash is fully considered.

The planting of cane varieties with loose leaf-sheaths is recommended. The variety P.O.J. 2878 should in no case be planted in infested centres of the Island.

Acknowledgments.

It is with the deepest sense of gratitude that the writer wishes to record here the unceasing help received from Mr. P. R. Hermelin, an extra officer who worked, under the author's guidance, on the study of the bionomics of the scale.

Special thanks are due to Mr. R. Mamet, who, at the author's request, kindly contributed the technical description of the scale.

Thanks are tendered to all the planters on whose estates observations were made for their ready co-operation.

Lastly, the author is indebted to Mr. A. de Sornay, B.Sc., of the Sugar Cane Research Station, who kindly contributed to the statistical analysis of the experiments described above.

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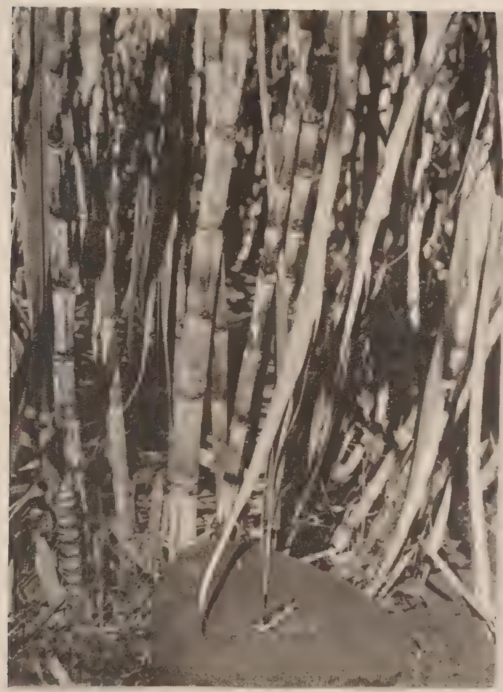

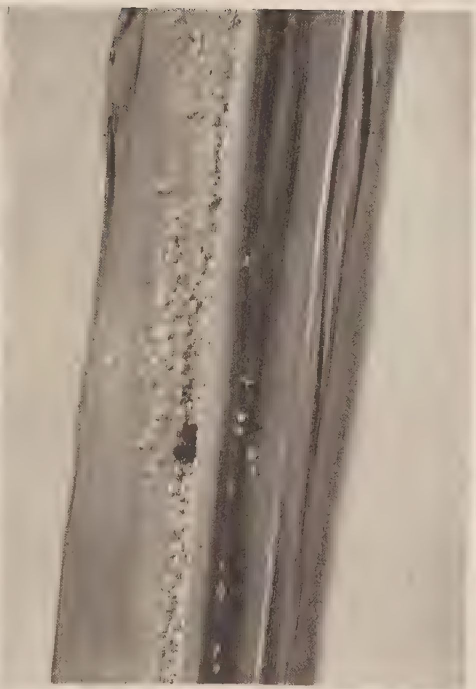

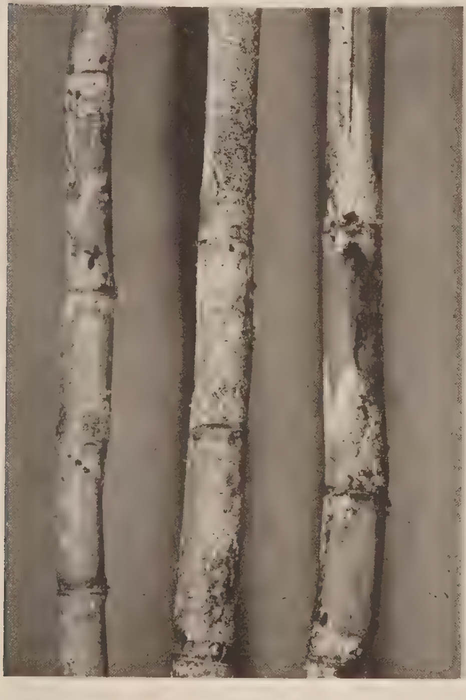

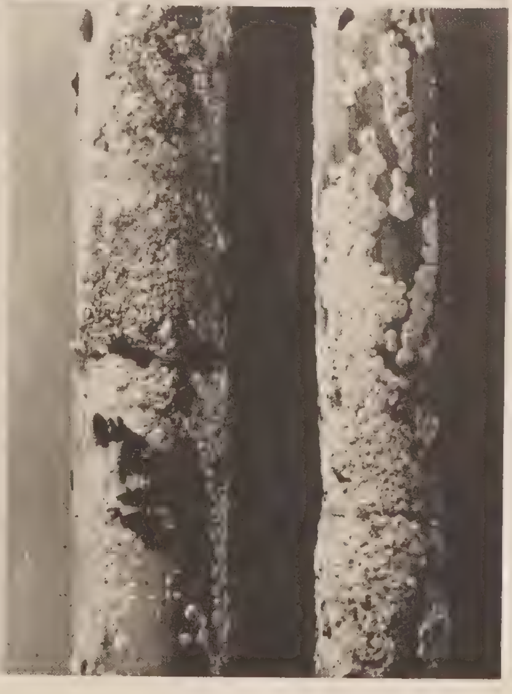

Fig. 1. Cane stools infested with *A. tegalensis*. Note the white crusts on the stems.

Fig. 2. Cane leaf showing scales thereon. Found only in cases of very severe infestation.

Fig. 3. Sugar cane stems showing scales (the black dots are Coccinellid larvæ).

Fig. 4. Enlarged section of Fig. 3.
Left: Coccinellid larvæ and nymphs.
Right: Nearly all scales parasitised by Chalcids.

FUMIGATION AS A METHOD OF CONTROLLING THE BODY LOUSE, *PEDICULUS HUMANUS CORPORIS*, DE GEER. PARTS I AND II.

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Introduction.

In 1909 Nicholl demonstrated that the body louse, *Pediculus humanus corporis*, was the vector of *Rickettsia prowazeki*, the causative agent of typhus, and it is now known to be concerned in the spread of trench fever and relapsing fever also. One has only to recall the havoc caused by the two first diseases during and immediately after the last war in order to appreciate the desirability of having as many methods of checking the spread of the body louse as possible.

During the war years 1914–1918, Bacot and Nuttall in Great Britain, and Sikora and Hase in Germany, investigated much of the biology and behaviour of the louse and developed methods of controlling it. Nuttall (1918) deals very fully with the control situation at the end of the last war, while the whole subject has been brought up to date by Buxton (1939).

The investigations reported by Nuttall and others covered control by dry heat, steam and fumigants. Of the latter hydrogen cyanide was favoured, presumably on account of its high toxicity and good penetration. It was utilised extensively in Central Europe and was also adopted by the American immigration authorities in the years following the last war (Trimble, 1925).

The hazards associated with the use of hydrogen cyanide as a fumigant are well known and have been tragically demonstrated on more than one occasion. Hydrogen cyanide has only a faint smell and lacks other warning properties, but when one is considering the fumigation of bedding and clothing, it has special dangers due to its adsorption by fabrics and later evolution when the materials are warmed either by the body or on being brought into a warm room. Nowadays the use of hydrogen cyanide as a fumigant is covered by safety regulations and chemical tests have been devised (Page, Lubatti & Gloyns, 1939) to detect the presence of residues of the gas in fumigated premises.

At the outbreak of the present war, the louse control position was as follows. Heat and steam were safe and known to give good results when properly controlled, but their application demanded special and usually rather cumbersome equipment. Of fumigants, hydrogen cyanide had been extensively used and was known to be satisfactory, but its special dangers limited its application to skilled operators. There was, therefore, a definite need for further methods of control, and this paper represents the first of a series which it is hoped to publish dealing with the development of methods of controlling lice by fumigation.

The work has been divided into two main stages. Under the first, the effect of several fumigants on various stages of lice and eggs isolated in all glass fumigation flasks is being examined. Under the second aspect, practical tests with the lice dispersed among varying numbers of blankets in various containers are being made.

The present paper is concerned with the first group of tests and deals with the apparatus employed and sorting tests carried out on 20 fumigants in order to select the most favourable for further tests.

Part I. Apparatus and Method.

Bovingdon (1934) has discussed the merits of various types of fumigation apparatus and described a very versatile equipment. For the present purposes, however, it seemed desirable to utilise simple methods since war-time conditions make it rather difficult to obtain anything in the nature of special apparatus without considerable delay.

If reasonably accurate results are to be obtained, the following points must be borne in mind:—

(1) Physical factors such as temperature which have pronounced effects on the efficiency of a fumigant must be controlled.

(2) It must be possible to apply an accurately known dose of fumigant and/or to estimate its concentration in the fumigation enclosure.

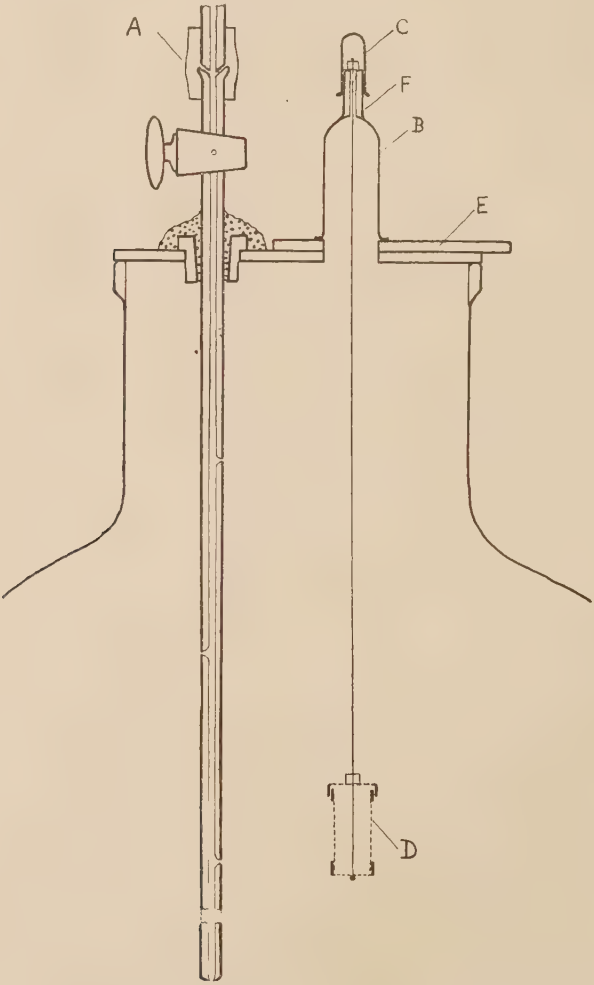

Fig. 1. Neck of fumigation flask showing mounting of capillary tubing and method of introducing the insects.

(3) The fumigant must be uniformly dispersed throughout the fumigation chamber.

(4) There must not be large absorption losses of fumigant on rubber bungs, etc.

(5) It must be possible to introduce the test insects under natural conditions.

The apparatus designed to cover the above points was as follows :—

A well lagged constant temperature box, internal dimensions 1½ ft. × 2 ft. × 1½ ft. fitted with a refrigerating unit, heating unit and a fan provided the constant temperature enclosure. With this equipment it was possible to maintain temperatures of 10, 20 and 30°C. within ± 0·2°C.

The fumigation chambers consisted of four 5·6 litre bolt neck round bottom flasks, having a ground flange on the neck. These flasks were supported in the constant temperature box with their necks terminating at the level of a felt-lined false top in four parts about 2 inches below the lid of the constant temperature box. Each flask was closed by a ground glass plate, diameter 3 in., attached to the ground top of the flask by a thin layer of Canada balsam. The ground glass plates carried two holes ½ in. in diameter. Through one a piece of thick-walled capillary tubing was mounted, while the other hole served to introduce the insects and the liquid fumigant. The mounting of the capillary tube was carried out by cementing round it the flanged neck of a small vial with glycerine-lead oxide cement, and this in turn was cemented in the hole in the glass plate with special wax on the outside. A better job could of course be made by a glass blower.

Fig. 1 represents the arrangement adopted.

The details of the capillary tube, the mounting of which has just been described, can be seen in the diagram. Attention may, however, be drawn to the fact that along its length, within the flask, the tube is perforated with 4 or 5 holes spirally arranged. The bore orifice at the end is constricted and each hole is a good deal narrower than the capillary bore. Air returning to the flask through these holes sets up a swirling motion in the flask and serves to mix the gaseous contents very thoroughly, as may be been if a little hydrochloric acid is added to the flask and the incoming air is passed through dilute ammonia. The ammonium chloride formed makes the swirling visible. The other point to note is the top of the capillary tube which is opened up and ground out to take the ground end of another piece of capillary connecting the flask to the outside of the constant temperature box. This, of course, reduces the rubber face exposed at the junction (A) to a minimum.

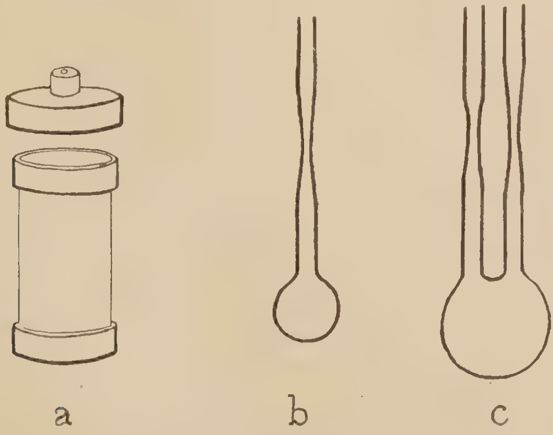

Fig. 2. Showing: *a*, insect cylinder and *b*, *c*, two types of liquid fumigant bulbs.

Fig. 1 also illustrates the provision made for introducing the insects without loss of fumigant. A ground glass plate E, 2 in. × 1¼ in. carries a round hole ½ in. diameter in the middle of one half. Over this hole a piece of tubing ½ in. internal diameter, with a flanged end, is mounted with balsam outside. The distal end is narrowed down and terminates in a short piece of narrow bore capillary tubing F, ground on the outside to take a small cap, C. The insect container consists of bolting silk mounted on glass rings—details may be seen in Fig. 2 a. The supporting cotton thread passes through the bottom of the gauze insect cylinder and its lid, which may have a small glass weight threaded on top of it. The cotton supporting the insect cylinder passes through F. Other details may be seen in the diagram. Only the simplest technique is involved in making and putting these parts together.

Provision was also made to supply the fumigation flasks with air conditioned to the temperature of the test and 50–60 per cent. relative humidity. This consisted of a glass spiral, two Woulff bottles containing diluted sulphuric acid, a bottle containing glass wool to hold back the acid spray and a desiccator in series, all immersed in a water bath maintained at the desired temperature. The desiccator was used to air the insects after the fumigation as described later. The whole was also boxed over and the air space maintained at approximately the desired temperature by means of electric light bulbs.

Breeding the Lice.

The technique for rearing lice has been fully described by Buxton. Briefly it consists in keeping the lice in small bolting-silk bottomed pill boxes held against the leg by means of an old sock top. The adults are provided with pieces of black tape on which to oviposit. The tapes are changed every two days so that eggs of known age are available for testing purposes.

In the present test, third-stage larvae and eggs up to two days old and between seven and nine days old have been used. After fumigation the lice are returned to pill boxes on the leg and the eggs to a desiccator at 70 per cent. R.H. in an incubator at 28°C. The lice are observed after 1, 2 and 5 days and the mortality assessed, counting only completely immobile insects as dead. Waving of the antennae is often the last sign of life. Different fumigants vary in their speed of action. Sometimes the insects appear to be unaffected and then die during the ensuing five days. Sometimes they are badly affected and never recover, or they may show a complete recovery or persist in a moribund condition. The eggs are allowed at least 14–15 days and any not hatched in this time are dead. The percentage mortality, using Abbot's formula, is assessed for lice, larvae and eggs.

Method of Operation.

Gaseous fumigants.

The flasks in the constant temperature box are connected up with the exterior by means of narrow bore tubing. The hole in the lid plate is covered with a piece of greased ground glass and the flask is evacuated and then allowed to refill with air conditioned to the required temperature and humidity. When each of the flasks has been prepared in this way, the ground glass squares are replaced by the plates carrying the loaded insect cylinders. At this stage the cylinders will be drawn up into the wide piece of tubing and held in position by replacing the ground glass caps over the cotton thread. The hole in the flask cover is now greased round and covered by the end of the ground plate E not carrying the tube B. In this way the surface of E exposed to the flask is free from grease. The flask is again evacuated and the measured dose of fumigants is introduced from a water jacketted gas burette. The flask is then allowed to return to atmospheric pressure with conditioned air.

In this stage the apparatus is allowed to remain for one hour, so that the temperature settles down and the insects also become conditioned to the temperature of the test before being exposed to the fumigant. At the end of this period the glass plate E is moved over and the two holes are brought into apposition. Cap C is removed and the insects' cylinder lowered into the flask. Cap C is now firmly replaced, making an airtight joint. The flask is rocked momentarily in order to swing the insect cylinder through the fumigant, and allowed to remain for the period of exposure.

Liquid fumigants.

These are weighed out into simple bulbs blown in narrow glass tubing or, if more convenient, as in the case of low b. p. fumigants, *e.g.*, ethylene oxide, into two armed tubes (fig. 2 b and c) (Lubatti, 1932). The former type are filled with a fountain pen type of pipette and the later by immersing in a freezing mixture and passing a stream of fumigant vapour through and allowing it to condense. The bulb is introduced into the fumigation flask after the first evacuation and just before the plate with the insect cylinder is placed in position. The flask is then re-evacuated and the bulb broken by shaking. It is not until these processes have been completed that the flask can be placed in the constant temperature box. It is then connected up to the conditioned air supply and again allowed the 1 hour conditioning period.

At the end of the test period, the insect cylinder is drawn up into B and, after E has been moved to its original position, a sample of the gas in the fumigation flask is drawn into an evacuated flask for analysis, noting the residual pressure in the fumigation flask. The insect cylinder is lowered out of B and complete with bulb and plate B and E is transferred to the desiccator in the air conditioning system. A slow stream of conditioned air is blown through the desiccator for 1 hour. At the end of the period the lice are transferred to gauze bottomed pill boxes and the eggs to an incubator, as described in the section on breeding of lice.

Part II. Preliminary Tests of Toxicity to Lice and Eggs.

Before attempting a detailed study of the dosage mortality relationship or the practical efficiency of any particular substance, a general survey was made of accepted fumigants and other substances which it seemed possible might be effective. Certain materials which had been previously suggested without adequate tests were also examined.

The method adopted in this general survey was to apply a dose of 10, 50, 100 mg./lt. or the saturation concentration to both lice (third stage larvae were used) and eggs, and to ascertain in which range the dose giving 100 per cent. mortality fell with a 1 hour exposure period at 20° C. using the technique described in Part I of this paper. The results obtained are set out in Tables II and IV.

The choice of a fumigant is not determined merely by its toxicity to the pest to be controlled, although this is ultimately the most important factor. It is necessary to give attention to physical and chemical properties since these determine its safety, availability, cost and general convenience, and may combine to outweigh the advantages of high toxicity. The thoroughly practical fumigant is, therefore, a compromise adopted to meet the special conditions under which the material will be used. Even when one pest on one class of goods is concerned as in this case (lice on clothing), the different types of fumigation enclosure available, the length of exposure considered practicable, the prevailing temperature and the experience of the operator, will all influence the choice of fumigant. Many of the factors which have a bearing on the choice of fumigant have been set out in Tables I and III. Those aspects of the tables which seem to need further comment are dealt with below. The main sources of the information contained in these tables are given in the references at the end of this section.

Comments on Tables I and IV.

The tables contain, among other data, the following column headings :—

Boiling Point, Specific Heat and *Latent Heat of Evaporation.*

From the data given in these columns the amount of heat necessary to vaporise the fumigant may be assessed. Low values mean rapid evaporation so that the fumigant will reach its maximum concentration rapidly. The boiling point also determines the type of provision which has to be made for packing and distributing the fumigant. Fumigants which demand heavy cylinders are at a disadvantage. The boiling points are given to the nearest 0·5°C.

Solubility in water.

Information relating to solubility in water is important since it affects penetration into clothing becoming limiting in the case of very water-soluble fumigants applied to damp clothing.

In order to simplify the data it has been expressed in the following way :—

——— =very soluble, from 50 cc. per 100 cc. water to infinity.
—— =under 50 cc. per 100 cc. water.
— =under 1 c.c. per 100 cc. water.

The saturation concentration.

This is given to the nearest 5 mg./lt. at 20°C. It measures the maximum content of fumigant attainable in the air space.

Inflammability.

The inflammability of the liquid fumigant is expressed as follows :—

——— =very inflammable or flash point below 0°C.
—— =inflammable or flash point above 0°C.
— =non-inflammable.

Toxicity to man and warning properties.

Both the acute toxicity and chronic effects resulting from repeated exposure to low doses have to be considered. Hydrogen cyanide is typical of the former and certain chlorohydrocarbons, *e.g.* tetrachlorethane of the latter. The following designations are employed :—

———— =very highly toxic—mainly acute.
——— =very toxic—mainly acute.
—— =toxic—mainly chronic.
— =relatively safe—about equal to petrol vapour.

A fumigant which in addition to being toxic is also rather difficult to detect, *e.g.* hydrogen cyanide, is very much more dangerous than one that is easily detected and obnoxious at very low concentrations, *e.g.* chloropicrin and trichloracetonitrile. The adequacy of the warning properties of a fumigant is therefore an important point. It has been expressed as follows :—

+++=warning properties adequate.
++ =warning properties inadequate.
+ =warning properties very inadequate.

Availability and types of package required.

These practical considerations assume greater importance during wartime conditions :—

+++ =commercially produced and readily available or easily generated from readily available materials.

++ =commercially produced, restricted supply.

+ =small commercial production.

— =not produced on commercial scale.

All materials dealt with in Tables III and IV can be packed in ordinary metal drums.

TABLE I.

Fumigant	Formula	B. P.° C.	Density	Solubility in water	Latent heat of evaporation cal./gm.	Saturation conc. in air 20°C. mg./lt.	Inflammability	Type of Package	Availability
Sulphur dioxide	SO_2	−10·0	1·434 0/4	– – –	–	∞	–	Cylinder or generator	+++
Hydrogen sulphide	H_2S	−60·0	1·191 0/4 A=1	– – –	–	∞	– –	,,	+++
Ammonia	NH_3	−33·5	0·597 15/15 A=1	– – –	–	∞	–	,,	+++
Ethylene oxide ...	$(CH_2)_2O$	10·5	0·896 0/4	– – –	14	1,850	– – –	Cylinder	++
Methyl bromide	CH_3Br	3·5	0·732 0/4	–	62·5	3,960	–	Cylinder or drum	++
Hydrogen cyanide	HCN	25·5	0·697 18 A=1	– – –	21·5	905	– –	,,	+++

TABLE II.

Fumigant	Odour	Warning properties	Toxicity to man	Dose in mg./lt. necessary to give 100% kill	
				Lice	Eggs
Sulphur dioxide	Strong choking	+++	– – –	10–50	10–50
Hydrogen sulphide ...	Strong sulphur characteristic	+++	– – – –	>100	0–10
Ammonia	Strong characteristic	+++	– – –	10–50	>100
Ethylene oxide	Mild resembling formaldehyde	++	– –	10–50	10–50
Methyl bromide	Mild	++	– –	10–50	10–50
Hydrogen cyanide ...	Mild	+	– – – –	10–50	0–10

TABLE III.

Fumigant	Formula	Density	B.P. °C.	Latent heat evap. gm. cal./gm.	Sp. ht. in gm. cal./gm.	V.P. in mm./Hg.	Solubility in water	Sat. conc. in air at 20°C. mg./lt.	Inflamma bility	Avail-ability
Methyl formate ...	$H.COO.CH_3$	0·967 25/4	31·5	112	0·478	478 (20°C.)	– –	1,695	– – –	++
Ethyl formate	$H.COO.C_2H_5$	0·924 25/4	54·0	97·5	0·510	195·5 (20°C.)	– –	837	– – –	++
Methyl acetate	$CH_3COO.CH_3$	0·927 25/4	57·0	98·0	0·502 (18°C.)	174 (20°C.)	– –	705	– –	++
Methyl monochlor-acetate	$CH_2Cl.COO.CH_3$	1·227 25/4	130·0	50·1	0·382	6·7(20°C.)	–	40	– –	–
Methylene chloride ...	CH_2Cl_2	1·326 20/4	40·0	79	1·20 (15°C.)	349 (20°C.)	– –	1,630	–	++
Ethylene dichloride ...	$CH_2Cl.CH_2Cl.$	1·253 25/4	83·5	77·5	0·305(30°C.)	63·0(20°C.)	–	345		++
Trichlorethylene ...	$CHCl. : CCl_2$	1·456 25/4	87·0	57·5	0·223(20°C.)	58(20°C.)	–	410	–	++
Tetrachlorethylene ...	$Cl_2C. : CCl_2$	1·608 25/4	121·0	50	0·216(20°C.)	14·5(20°C.)	–	132	–	++
Tetrachlorethane ...	$CHCl_2.CHCl_2$	1·5945 20/4	146·0	55	0·268(20°C.)	4·5(20°C.)	–	44	–	++
Carbon tetrachloride ...	CCl_4	1·5845 25/4	76·5	46·5	0·202(20°C.)	91·0(20°C.)	–	775	–	++
Chloropicrin	CCl_3NO_2	1·651 20/4	112·0	59	0·235	16·9(20°C.)	–	184	–	++
Trichloracetonitrile ...	CCl_3CN	1·44	85	70	0·20	53 (20°C.)	–	552	–	–
Carbon disulphide ...	CS_2	1·266 20/4	46·0	84	0·242(20°C.)	298 (20°C.)	–	1,250	– – –	++
Methyl allyl chloride ...	$CH_2{=}\underset{\textstyle CH_3}{\underset{\vert}{C}}{-}CH_2Cl$	0·925 20	72·0	89	0·46	102 (20°C.)	–	505	– –	+
Isobutyl formate ...	$H.COOCH_2CH(CH_3)_2$	0·8835 20/4	100·0	78	?	84 (40°C.)	– –	472	– –	+

TABLE IV.

Fumigant	Odour	Warning properties	Toxicity to man	Dose in mg./lt. necessary to give 100% kill	
				Lice	Eggs
Methyl formate	Mild	+++	–	50–100	100–S
Ethyl formate	Mild	+++	–	50–100	100–S
Methyl acetate	Mild	+++	–	100–S	>S
Methyl monochloracetate	Mild	++	?	0–10	0–10
Methylene dichloride ...	Mild	+++	–	100–S	100–S
Ethylene dichloride ...	Mild	+++	–	100–S	>S
Trichlorethylene	Mild	+++	–	100–S	>S
Tetrachlorethylene ...	Mild	+++	–	100–S	>S
Tetrachlorethane ...	Mild	++	– –	10–S	>S
Carbon tetrachloride ...	Mild	++	– –	100–S	>S
Chloropicrin	Characteristic lacrymatory	+++	– – – –	0–10	10–50
Trichloracetonitrile ...	Oxides of nitrogen lacrymatory	+++	– – – ?	10–50	50–100
Carbon disulphide ...	Strong	++	– –	100–S	100–S
Methyl allyl chloride ...	Mild-Strong	++	– –	50–100	100–S
Isobutyl formate	Mild	+++	–	50–100	100–S

Review of Fumigants in Tables I and II.

During the course of the work it became apparent that many of the fumigants would not be suitable for the purposes intended at the concentration necessary to kill the lice and nits, owing to the damage to certain classes of article among those to be treated. This is true of sulphur dioxide, hydrogen sulphide and ammonia. The latter two were also excluded because of their low toxicity to the lice in the case of hydrogen sulphide and the nits in the case of ammonia.

Ethylene oxide was excluded because it has to be handled in heavy cylinders, methyl bromide because it was in short supply—it has subsequently become more available—and hydrogen cyanide was only included because of its comparative interest. Its high toxicity to man and ready absorption on fabric would in any case make it undesirable for this type of work.

None of the fumigants in this section was given more than very preliminary practical tests.

Review of Fumigants in Tables III and IV.

The methyl and ethyl formates have been chosen for practical tests because they are fairly toxic to lice and nits and comparatively harmless to man. Methyl acetate is not sufficiently toxic, whilst methyl monochloracetate is not available in bulk quantities.

Most of the chlorinated hydrocarbons were not sufficiently toxic to make them interesting. However, ethylene dichloride is very readily available and has therefore been included in five hour tests where it is satisfactory.

Chloropicrin was included in the practical tests because of its high toxicity. It demands too much care, however, to be handled by inexperienced personnel. Trichloracetonitrile has been tested since it is very toxic and generally effective. It is highly lacrymatory, but if it could be made available would be preferable to chloropicrin in the hands of trained operators. Carbon disulphide is too inflammable and ineffective to be considered as a practical proposition. Methyl allyl chloride has been fully tested. Above 20°C. it is a good fumigant, which can be handled with comparative safety and is to be recommended.

From the above lists the following materials have been selected for practical tests: Methyl formate, ethyl formate, methyl allyl chloride, trichloracetonitrile, ethylene dichloride, and chloropicrin. The practical tests will be described in full in a later paper.

Acknowledgments.

This work has been carried out at the suggestion of Professor P. A. Buxton under a grant from the Medical Research Council. I am especially indebted to Professor Buxton for advice, while Dr. V. B. Wigglesworth of this department, and Drs. A. Page and O. Lubatti, Imperial College, have also kindly given advice when needed.

Summary.

A method for fumigation experiments has been worked out, and preliminary tests on 21 substances are reported. The dosage-mortality relationships of about 10 of these are being worked out in some detail, while six have been chosen for practical tests. It is hoped to make reports on these two aspects later.

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A NEW INJURIOUS MEALY-BUG FROM THE GOLD COAST.

By F. Laing.

The following is a description of a new mealy-bug occurring on cacao in the Gold Coast, which is reported by the collector, Mr. H. E. Box, to be one of the Coccid vectors (*Ferrisia virgata* being another) of the " swollen-shoot " virus disease of cacao.

Pseudococcus exitiabilis, sp. n.

Very imperfect material for describing external characters only available ; the species would appear to be more or less completely covered with a floury coating, thinner along the intersegmental areas, and have a complete series of marginal filaments of medium length, the anal pair being longer than the others ; where the white deposit has been scraped away, the underlying cuticle appears sooty black or presents a greyish-ochraceous look.

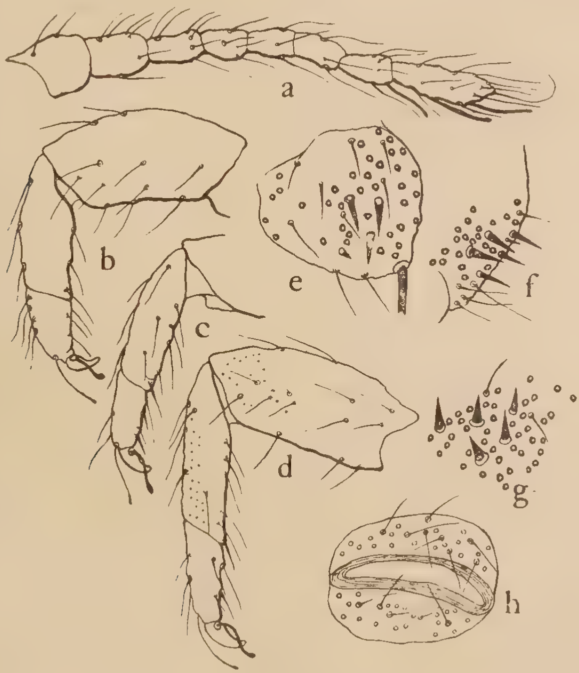

Fig. 1. *Pseudococcus exitiabilis*, sp. n. *a*, antenna ; *b, c, d*, 1st, 2nd, 3rd legs ; *e, f, g*, 18th, 17th, 1st cararius ; *h*, posterior ostiole.

Female, when mature, broadly ovate, the mean breadth to the length being in the proportion of 1 : 1·5 ; anal lobes projecting slightly from the body line ; antennae normally 8-segmented, the proportional lengths being (1) 20 ; (2) 20 ; (3) 20 ; (4) 15 ; (5) 17 ; (6) 17 ; (7) 15 ; (8) 36 ; seventh segment with one strong, blunt, subapical seta, the eighth with three, one submedian and two subapical ; a few filiform, rather long setae on each segment ; in some specimens the antennae are 7-segmented, fusion occurring apparently between the fourth and fifth. Rostrum broad and short, reaching just beyond the first pair of coxae, several setae on apical segment and a compact lateral group of three on either side subapically. Legs conspicuously short and robust, the average proportions of the various parts being :—

Leg	Femur		Tibia		Tarsi	
	Length	Breadth	Length	Breadth	Length	Breadth
I ...	80	40	54	18	30	15
II ...	80	37	60	17	30	20
III ...	90	40	75	16	35	16

Minute pores present on the coxae and on the tibiae of the hind leg, mainly along the outer longitudinal half, also but not apparently regularly, distally on hind femur, these being difficult to discern ; both tarsal and ungual digitules long, clavate, former slender, filiform, latter more robust. Cerarii consisting of 18 pairs, well defined, with the area surrounding each slightly sclerotised but not circumscribed, each with a variable number of spines, the corresponding pairs on either side not always agreeing, spines also of different sizes, the following figures being averages of several counts : (18) 3–4, occasionally 2 ; (17) 5–6 ; (16) 4–5 ; (15) 4–5 ; (14) 4–7 ; (13) 5–6 ; (12) 4–5 ; (11) 4–5 ; (10) 3–6 ; (9) 4 ; (8) 4–5 ; (7) 4–5 ; (6) 2–3 ; (5) 2–4 ; (4) 3–4 ; (3) 4–7 ; (2) 3 ; (1) 3–4 ; slender auxiliary setae present on all cerarii, scanty as a rule on the intermediate, but quite definite on the posterior and anterior ; cerarian pores numerous but not densely crowded, those on the more anterior groups being, if anything, closer together ; paranal cerarius with an oblique ventral bar. Whole body with numerous small, triangular, trilocular pores ; ventrally an irregular, not always too well defined series of large disc pores on the three posterior segments and a much weaker fourth series ; a general vestiture of rather long, uniform, filiform setae of medium density ; both anterior and posterior ostioles quite strong, rims fairly thick, lips with 6–8 setae and pores of about the same density as on the body ; median ventral cicatrice, when not collapsed, slightly broader than long.

Length 2·4 mm. ; breadth 1·8 mm.

GOLD COAST : Tafo, on *Theobroma cacao* (*G. S. Cotterell* and *H. E. Box*).

The species has normally eight antennal segments, one or two specimens of the series examined exhibiting seven segments only or even four where the whole antenna is foreshortened, the second and fourth segments being greatly elongated, doubtless the result of an accident. In one specimen 37 cerarii were noted.

As to the affinities of this new species, it belongs to a small, very closely allied group of mealy-bugs comprising *P. hispidus*, Morr., found in Malaya, *P. jacobsoni*, Green, occurring in Sumatra, and *P. njalensis*, Lg., known only from Sierra Leone. Its relationship to *P. njalensis* is so close that further experience of the two species may result in their union. The points of difference between the two are comparative. In *P. njalensis* the cerarian pores are not so numerous nor quite so densely crowded, particularly on the interantennal groups, the cerarian spines tend to be longer, more slender and rather fewer in number especially anteriorly, the rostrum is relatively longer, the rims of both pairs of ostioles not quite so firm, the hind femur appears to be without pores (not that these are always evident in the new species), and the combined length of the tibia and tarsus of the hind leg in relation to the length of the femur tends to be shorter, but otherwise in the general vestiture and other characters the two are remarkably similar.

The Status of the Name Pseudococcus.

I use the generic name of *Pseudococcus* because of its present-day association with the mealy-bugs, but the position is worth stating afresh. In the Fernald Catalogue, 1903, the type was fixed as *longispinus* T.T. This is what Westwood, the founder of the genus, says (Introd. Mod. Class. Insects, **2,** p. 447, footnote, 1840) regarding *Pseudococcus* " . . . the latter (*i.e. Lecanium hesperidum*, &c.) may retain the name of *Lecanium*, *C. ilicis* that of Coccus, and *C. cacti* that of Pseudo-Coccus " and again on p. 448 " . . . this insect (i.e. the Cochineal) which has been imported by the French into Algiers, and by the Spaniards into Spain, with apparent success, and which is to be found in many of our hot-houses on the Cacti, belongs to a genus distinct from the preceding (*i.e. Porphyrophora*) and which I propose to name Pseudo-Coccus, the male . . . " The caption on p. 445, fig. 118. 7. Pseudoccus W. cacti L. is a misprint. There can be no doubt as to what Westwood considered the type. It is quite true that in the " Synopsis " p. 118, 1840, Westwood associated *C. adonidum* and *C. cacti* under *Pseudococcus*, but this does not invalidate the statement he makes in the text, while Professor Cockerell tells me (*in litt.*) that because *cacti* was " satisfied " generically under *Dactylopius*, he advised Mrs. Fernald to use the other species, *adonidum*, *i.e. longispinus*, as type of *Pseudococcus*. The position is all the more regrettable in view of the fact that Kirkaldy (Entom., **37,** 1904) drew attention to the point twice, on p. 227, footnote, and p. 258, where he says " *Pseudococcus* . . . is therefore a pure synonym of *Dactylopius* Costa ; for *Pseudococcus* Fernald, *Trechocorys* Curtis must be used, type *adonidum* (nec Linn.)=*longispinus* (Riley)." Had attention been paid at the time when *Dactylopius* was in general use for the mealy-bugs, and before *Pseudococcus* was adopted, the change to *Trechocorys* would have been simple, and however reluctant I may be myself to see the present nomenclature upset, yet I cannot visualise the whole weight of the International Commission being invoked to make *Pseudococcus* a *nomen conservandum* in order to uphold a simple mistake.

Though this is not the place to deal fully with the position of *Lecanium*, it may be mentioned that Westwood (*op. cit.*) has fixed *hesperidum* as the type, making it thus a synonym of *Coccus*, as set by Latreille, 1802, and that even if he were held not to be antedated by Mrs. Fernald herself (Canad. Ent., **34,** p. 232, 1902) where she says " If, therefore, we adopt *hesperidum* as the type of *Coccus*, the genera *Calymnatus* and *Calypticus* of Costa and *Lecanium* of Burmeister will fall as synonyms of *Coccus*." Sanders's fixation (J. econ. Ent. **2,** p. 430, 1909) of *persicae*, Geoff., as type will not stand, *Eulecanium*, Ckll., remaining available for this genus.

TESTING INSECTICIDES ON THE ARGASID TICK, *ORNITHODORUS MOUBATA*, MURRAY.

By G. G. Robinson,
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Y. C.

Introduction.

This paper embodies the result of three years' search for one or more insecticides for use against *Ornithodorus moubata*, Murray. This tick is the vector of human relapsing fever in Central Africa and has proved very resistant to all but a very few insecticides. Indeed, it furnishes a good example of the selective response to various insecticides seen in many insects (Busvine, 1942). Its response to pyrethrum and rotenone has already been reported (Robinson, 1942 a and b) ; tests have now been done on a great variety of other substances, and the whole work is here reviewed.

The experiments were essentially sorting tests designed to show whether or not a given substance was worth further trials.

Methods.

Two main classes of insecticides were investigated—sprays and dusts. Among the latter there occurred several volatile substances which showed toxicity as fumigants, but these solids were not particularly investigated because their use is limited to confined spaces such as the soil atmosphere.

Various oily diluents were used for administering sprays : Shell oil P31, Shell odourless distillate, ground-nut oil and xylenol, specifications of which are given in a previous paper (Robinson, 1942 a).

Of these diluents, P31 oil proved most toxic (Table I, *b*). In sufficient dose, it saturated the tick's cuticle and occluded the spiracles, death being caused by suffocation (Robinson, 1942 b). Ground-nut oil acted similarly. Odourless distillate did not cause suffocation as, owing to its high volatility, it soon evaporated from the tick's cuticle. It was definitely toxic, however, and caused symptoms such as twitching of the legs and hyperactivity of the coxal glands which often led to death. Xylenol sometimes induced temporary coma, and in sufficient quantity caused suffocation like P31 oil. If a substance is to be of use as an insecticide, it must show strong activity in a diluent at a dosage below the median lethal dose of the latter, and at a concentration not too high for economic, medical or other reasons.

The method of dosing was the same as that described in a previous paper (Robinson, 1942 b). Engorged ticks were lightly fixed on their backs to strips of index card by a smear of rubber solution, and subjected to spraying in a Potter tower (Potter, 1941). In this way the spray gained access to the articular membranes of the legs which appear to afford comparatively easy penetration of the insecticide. Spraying the dorsal surface had proved unsatisfactory because of the thickness of the cuticle in this region. Death ensued only when a large enough dose for suffocation had been administered (Robinson, 1942 b).

In the present experiments, the standard method was to spray ten ticks at each of five graded dosages. After treatment they were returned to the incubator where they had been reared (30°C., 50 per cent. relative humidity). After about two hours had elapsed, they were released from the cards on to clean filter paper. Usually mortalities could be safely assessed after two days.

In the dusting experiments, ticks were confined in a dish with the finely ground material in most cases undiluted. If no action took place overnight, the dust was considered no good. If action did take place, then dilutions with raw Kaolin or talc were tried.

The results are shown in Tables I and II.

TABLE I.

Liquids used as sprays against 3rd stage nymphs of Ornithodorus moubata *(at least* 50 *ticks per dose-range). The median lethal doses are given in mg. fluid/cm^2. A plus sign indicates that the MLD is more than the dose stated. The figures in brackets are the percentage mortalities at these sub-median doses.*

Spray Fluid	M.L.D. in mg/cm^2
(*a*) *Vegetable derivatives.*	
Pyremist " L " (0·15% wt/vol. pyrethrin I in P31)	0·110
Pyremist " L " +10% isobutyl undecyleneamide	0·110
Pyremist " L " (a different sample, 0·1% wt/vol. pyrethrum I in P31)	0·070
Pyremist " L " +20% pine-oil	0·068
Pyremist " L " +10% sesame oil	0·077
1% nicotine in ground-nut oil	+0·160 (10)
1·5% rotenone in xylenol, ground-nut oil and P31 (5 : 3 : 12)	0·047
(*b*) *Oils.*	
P31	0·160
Odourless distillate	0·220
Ground-nut oil	0·360
Croton oil—50% in P31	+0·160 (0)
Cashew-shell oil—20% in P31	+0·220 (10)
(*c*) *Coal-tar distillates* used neat except the tar-base.	
Xylenol (B.P. 210–220°C.)	0·310
Phenols (B.P. 250–300°C.)	+0·350 (0)
Crude high temperature tar-oil (B.P. 280–360°C.)	+0·350 (20)
Low temperature tar-oil (B.P. 300–360°C.)	0·470
Tar-base (20% in P31 and ground-nut oil : 4 : 1)	+0·280 (0)
Chlorinated cresylic acid (approx. 50% chlorine)	+0·360 (10)
(*d*) *Thiocyanates.*	
n-octyl	+0·250 (10)
n-decyl	+0·170 (10)
n-dodecyl—50% in P31	0·170
n-tetradecyl	+0·140 (20)
n-hexadecyl	+0·120 (20)
n-octadecyl—50% in P31	+0·130 (0)
cetyl	0·230
Crude secondaries (prepared from C$_{10}$–C$_{18}$ olefines) 25% in odourless distillate	0·270
Refined secondaries—25% in odourless distillate	0·340
Lethane 384 (50% β-butoxy. β″-thiocyanodiethyl ether in odourless distillate). 50% in P31	+0·250 (0)
Lethane Special (37·5% thiocyanethyl laurate, 12·5% β-butoxy. β″-thiocyanodiethyl ether, 50% odourless distillate). 50% in P31	+0·260 (20)
(*e*) *Miscellaneous.*	
Alpha-naphthylamine—20% in ground-nut oil	+0·310 (0)
Alpha-naphthol—20% in ground-nut oil	+0·310 (10)
1-chlor. 2.4–dinitrobenzene—10% in P31, ground-nut oil and coal-tar creosote (2 : 1 : 1)	+0·240 (10)
Paradichlorbenzene—10% in P31	0·250
Benzyl benzoate—25% in odourless distillate	0·420
2-benzthiazyl-ethyl-sulphide—50% in P31	+0·310 (0)
Copper naphthenate 10% in medicinal paraffin and odourless distillate (1 : 4)	0·240
Isobutyl undecyleneamide—20% in P31	0·160
" Thanite " (Fenchyl thiocyanacetate) 25% in odourless distillate	0·270
Dixanthate—10% in P31	+0·360 (0)
2.4-dinitroanisole—5% in xylenol and ground-nut oil (1 : 1)	+0·310 (0)
Tetraethyl thiuram monosulphide—10% in ground-nut oil	+0·270 (0)
DDT (Dichlor-diphenyl-trichlorethane) in P31 and odourless distillate (19 : 1)	+0·370 (10)

TABLE II.

Solids used as dusts against Ornithodorus moubata. *Ticks were subjected to excess of material for* 20 *hours in an open dish at* 28°C. *and* 50 *per cent. relative humidity. Fed 3rd stage nymphs were used except in* (f) *where unfed 4th stage nymphs or females were used as stated.*

Material	Result
(*a*) *Hydrocarbons.*	
Acenaphthene, anthracene, fluorene, phenanthrene	Inert
(*b*) *Phenol homologues and derivatives.*	
p-chlor-m. xylenol, catechol, resorcinol, hydroquinone, 2.4-dinitroanisole, p.cyclohexylphenol, trichloro.6-nitrotoluene : Kaolin : : 1 : 1 ...	Inert
p.chlorphenol, tertiary butyl phenol, p-toluidine, 1.2.4-xylenol, 1.3.2-xylenol, 1.4.5-xylenol, 1.3.5-xylenol ...	Active as fumigants but volatilise in a few hours
2.4.5-trimethylphenol ...	Weak narcotic
3.4.5-trimethylphenol ...	Kills 1/5 in 4 days
3-methyl.6-ethyl.phenol—25% in Kaolin ...	Kills 4/5 by contact action ; slowly volatile but vapour not toxic
10% in Kaolin ...	Kills 2/5 in 4 days
2.4-dinitrophenol—20% in Kaolin ...	Kills 5/10 in 3 days 9/10 in 7 days
3.5-dinitroorthocresol—20% in Kaolin ...	Kills 6/10 in 2 days 10/10 in 5 days
(*c*) *Bases and derivatives.*	
Aniline hydrochloride, acetanilide, p-chloracetanilide ...	Inert
Diphenyl ...	Slow contact narcotic
Carbazole, alpha-acetnaphthalide, alpha-chlor-beta-acetnaphthalide ...	Inert
(*d*) *Derivatives of naphthalene.*	
Naphthalene, beta-chlornaphthalene, beta-methylnaphthalene	Active as fumigants but volatilise in a few hours
2.6-dimethylnaphthalene, 2.7-dimethylnaphthalene, beta-naphthaquinone, sodium beta-naphthalene sulphonate, sodium naphthalene-1.6-disulphonate, sodium naphthalene-2.6-disulphonate, sodium naphthalene-2.7-disulphonate, formyl-alpha-naphthalide, acet-alpha-naphthalide, propion-alpha-naphthalide, benzoyl-alpha-naphthalide, benzoyl-sulphonyl-alpha-acetnaphthalide, alpha-naphthyl-urea, alpha-naphthyl-thiourea ...	Inert
alpha-naphthol ...	Slow contact narcotic acting only after 3 days
(*e*) *Various amines and related compounds.*	
Hexamine, sulphonilamide, sulphapyridine, thiazamide, o-phenylene diamine, p-phenylene diamine, diaminonaphthalene, beta-naphthylamine, 2-nitro-alpha-naphthylamine, 4-nitro-alpha-naphthylamine, thiocarbamide, salicylamide, phthalimide, p-dimethylene amidobenzaldehyde, semioxamazide, p-xenyl carbamide, 3-hydroxydiphenylamine ...	Inert
Diphenylamine ...	A slowly volatile fumigant producing deep narcosis with recovery after 6 days
Alpha-naphthylamine ...	Strong contact narcotic from which recovery ensues after a fortnight

TABLE II—*continued.*

Material	Result
(*f*) *Various solids.*	
Flowers of sulphur, sulphur-naphthalene : : 2 : 1, sulphur : slaked lime : : 1 : 1, sodium fluoridecalcium arsenite (50% in Kaolin)	Inert
Corundum	Kills 4/10 in 6 days
Nicotine bitartrate (10% in Kaolin)	Rather slow narcotic
Rotenone : coal-tar phenols (B.P. 250–300°C.) : talc : : 1 : 10 : 100	Kills 1/20
Pyrethrum powder : Kaolin : : 100 : 0	Kills all ♀♀
50 : 50	Kills 7/10
25 : 75	Kills none
Pyrethrum powder : Kaolin : : 25 : 75.	
On dry filter paper	Kills none
On wet filter paper	Kills all
Dixanthate—10% in talc. Potassium ethyl xanthate—50% in Kaolin	Inert
Tetraethyl thiuram monosulphide—50% in Kaolin	Kills 1/5 after 8 days
DDT (dichlor-diphenyl-trichlorethane)	Kills 1/10 after 3 days Kills 4/10 after 6 days

Summary.

The sprays containing pyrethrum were outstanding in their high toxicity to the tick, and should be used where spraying measures are employed until a substance is discovered of the same order of toxicity.

Of the dusts, pyrethrum powder was again outstanding in its activity. If it is to be used, tests should be done beforehand to make certain that the sample is a good one.

Other dusts were tested because pyrethrum powder is likely to deteriorate rather rapidly in the field. Certain derivatives of phenol and naphthalene were active as fumigants. Although these substances would evaporate quickly in contact with the general atmosphere, they might have some use as soil-fumigants in the floors of huts. Other derivatives acted purely as contact poisons and yet were just too volatile to be lasting in the general atmosphere. Alpha-naphthylamine and 3-methyl.6-ethyl.phenol are examples. Of these two, the latter is more toxic, and it is possible that the substitution of a higher alcohol for the methyl or ethyl group would decrease the volatility but not the toxicity.

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Dr. F. Tattersfield and his staff at Rothamsted Experimental Station have kindly estimated the pyrethrin I content of samples of Pyremist " L," and have also supplied me with pure rotenone.

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Lastly, it is a pleasure to thank Professor P. A. Buxton, F.R.S., for many useful suggestions and for the interest he has taken in the work.

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FUMIGATION AS A METHOD OF CONTROLLING THE BODY LOUSE, *PEDICULUS HUMANUS CORPORIS*, DE GEER.

PART III. PRACTICAL TESTS.

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Introduction.

An earlier paper (David, 1944) described " in vitro " tests in which the approximate doses of twenty-one chemicals necessary to give a complete kill of lice and nits (*Pediculus humanus corporis*, De Geer) with a one hour exposure at 20°C. were determined. The results obtained made it possible to select certain of the materials for practical trials.

Inspection of the literature relating to the chosen fumigants shows briefly that the formates have been considered as fumigants on various occasions (Cotton & Roark, 1928, Simmons & Barnes, 1935), but the information is not extensive. However, during the course of this work a Russian paper (Evreynova and others, 1942) recommended the use of methyl formate for delousing garments. The very extensive literature on chloropicrin from 1848–1932 has been collected (Roark, 1934) and special attention may be drawn to the work of Moore (1918) and Moore & Hirschfelder (1919) on chloropicrin for body louse control. More recently (Sherrard, 1942) chloropicrin has been recommended for vermin control but lice were not among the organisms tested. Methyl allyl chloride (methallyl chloride) has been recommended as a fumigant by Briejèr (1938 & 1939 a, b) and Peters (1939) has also investigated its properties. Trichloracetonitrile is a comparatively new fumigant ; it has been used for controlling an orchard pest (Busbey, Yust & Fulton, 1942) while extensive house fumigations have been carried out in Germany (Peters, 1940) and the results were reported to be very satisfactory.

In passing from " in vitro " tests to practical fumigations, two factors, sorbtion losses and leakage losses of fumigant, assume greatly increased importance. It follows that the necessary practical dose has to be established by experiment, and the available concentration of fumigant to be assessed either by its effect on bags of insects placed amongst the material being treated or by chemical means. In the present case the biological method was used first. A dose of fumigant equal to several times that applied in the flask tests was introduced into the chamber. Starting from this point the dosage was adjusted until one was found which gave a complete kill of lice and eggs on the majority of occasions. When this minimum dose had been established, the distribution of the fumigant in the chamber was investigated chemically.

To a certain extent the results obtained in practical fumigations are applicable only to the particular conditions of the test. Included among these conditions are leakage losses from the chambers, nature, humidity, temperature and mode of packing goods as influencing sorbtion and penetration, and method of dispersal of fumigant. It is impossible to investigate the influence of all these factors on the effectiveness of the fumigant within a limited period, so that the figures for recommended dosage given later in the report are, strictly speaking, only accurate when the same conditions are reproduced.

The Test Insect.

The lice were bred as described by Buxton (1939). For these tests third stage larvae or adults, and tapes bearing two-day old and approximately eight-day old nits (eggs) were used. Before the exposure they were conditioned for an hour or so at the test temperature and at the conclusion they were allowed a similar period of airing. The eggs were subsequently returned to an incubator and the lice to feeding boxes. Controls were kept and treated in a similar manner.

The Practical Problem.

A brief consideration of the incidence of lousiness and the need for control leads to the conclusion that fumigation techniques to meet the following circumstances are desirable :—

(*a*) A method of dealing with small quantities of clothing. This should be adaptable for use in the home, for treating the clothes of people admitted to institutions or for disinfesting the clothing of people making contact with lice during the course of their work.

(*b*) A large-scale method which can be applied to all the property of a group of people simultaneously.

These two problems are rather distinct and are dealt with separately.

The Small-Scale Practical Fumigation.

The fumigation may be carried out in any reasonably impervious container, such as a tin box, chest, trunk or domestic ash bin. For the purpose of the tests described in this paper, ash bins of 3·7 cubic feet capacity filled with seven or eight blankets were employed.

The same simple procedure may be followed in all cases. This consists of measuring out the required dose of fumigant into a bottle with a perforated metal cap and sprinkling it on to the garments after each has been placed in the bin. If the quantity of fumigant is small, it is only necessary to treat every other garment or so, depending upon the volume to be applied. It is, however, important to distribute the fumigant evenly from bottom to top, keeping if anything rather more than half for the upper layers of clothing, since the heavy fumigant vapours sink to the bottom. The bin should be filled as quickly as possible and when all the garments are in place, it is advisable to tuck in a clean article over the pile before putting down the lid, as this helps to ensure that the uppermost garment is adequately fumigated. At the end of the prescribed period or longer, the garments are removed and aired. During fumigation the bin should be sheltered from the wind, otherwise the lethal concentration may not be reached in the upper layers.

Small-Scale Experimental Fumigation.

For the purpose of the test fumigations, the bins were fitted with sampling tubes near the top and bottom, and also during packing, bags of lice and eggs were introduced amongst the blankets, one near the bottom and the other under the top blanket. In order to avoid contact with liquid fumigant the bags were placed under eight folds of blanket, before the fumigant was applied. Before a test fumigation was carried out the blankets were prepared by maintaining them at the required temperature overnight. Between tests the blankets were aired out-of-doors.

Dosage for Bin Fumigations.

The actual dose necessary to give a complete kill was established by trial and error and the result once ascertained was only accepted after confirmation. Each of the dosages set out in the following table is supported by several tests. Altogether 170 test fumigations were carried out to establish the data in Table I.

TABLE I.

Bin tests—quantity of fumigant required at various times and temperatures. The dosages are given in mg./lit. (=oz. per 1,000 cu. ft.), followed by c.cm./cu. ft. which is convenient as a practical measure.

Fumigant	Exposure Conditions								
	1 Hour			2 Hours			5 Hours		
	10°C.	20°C.	30°C.	10°C.	20°C.	30°C.	10°C.	20°C.	30°C.
Methyl formate :									
mg./lit.	1295	925	—	925	735	—	650	460	—
c.cm./c.ft.	38	27	—	27	21·5	—	19	13·5	—
Ethyl formate :									
mg./lit.	980	785	525	785	620	360	360	260	260
c.cm./c.ft.	30	24	16	24	19	11	11	8	8
Methyl-allyl chloride :									
mg./lit.	1340	620	260	1080	260	130	260	130	90
c.cm./c.ft.	41	19	8	33	8	4	8	4	2·75
Ethylene dichloride :									
mg./lit.	—	—	—	—	—	—	2170	1910	1465
c.cm./c.ft.	—	—	—	—	—	—	49	43	33
Trichloracetonitrile :									
mg./lit.	610	280	205	280	205	205	140	70	70
c.cm./c.ft.	12	5·5	4	5·5	4	4	2·75	1·35	1·35
Chloropicrin :									
mg./lit.	—	470	235	1410	470	160	235	80	80
c.cm./c.ft.	—	8	4	24	8	2·75	4	1·35	1·35

At the end of the prescribed period the articles are removed from the bin, shaken out in the air and given a fifteen-minute airing period, or longer if required. The precautions necessary in handling the various fumigants are discussed later, in the section on "Choice of Fumigants."

The Influence of Length of Exposure and Temperature on the Necessary Dose in Bins.

Useful information concerning the most efficient working conditions can be obtained by plotting the results given in Table I so as to show the relationship between dosage and time. Graphs I, II and III (fig. 1) give the dose/time relationship at 10, 20 and 30°C. The graphs show effective dosages under varying conditions of time and temperature and sum up the results of the complex interaction of several factors. Among these factors are the decrease in sorbtion and time of evaporation of fumigant with increase in temperature and decrease in lethal dose with time and temperature. In view of the number of replicate tests made, it is perhaps justifiable to assume that the apparently anomalous behaviour of certain of the fumigants is dependent upon the complex interaction of these various factors and their relative influence under different conditions, and not to other errors.

Fig. 1, Graph I for 10°C., shows that it is particularly advantageous to prolong the time with methyl-allyl chloride and chloropicrin up to five hours, less so for methyl and ethyl formate and only slightly so for trichloracetonitrile beyond two hours. It will be noted that the methyl-allyl chloride effective-dosage/time curve cuts that for methyl and ethyl formate and also that for a two-hour exposure at 10°C. the same volume of chloropicrin and ethyl formate is needed.

At 20°C. (fig. 1, Graph II) the decrease in dosage with time remains about the same for the two formates but is much less marked for methyl-allyl chloride and chloropicrin. It will be noted that in these tests methyl-allyl chloride and chloropicrin are equally efficient in a two-hour exposure, but that for one-hour and five-hour tests chloropicrin is more efficient.

At 30°C. (fig. 1, Graph III) the order of dosage of fumigants is largely dominated by the actual toxicity of the fumigants, and no great advantage results in prolonging the exposure beyond two hours.

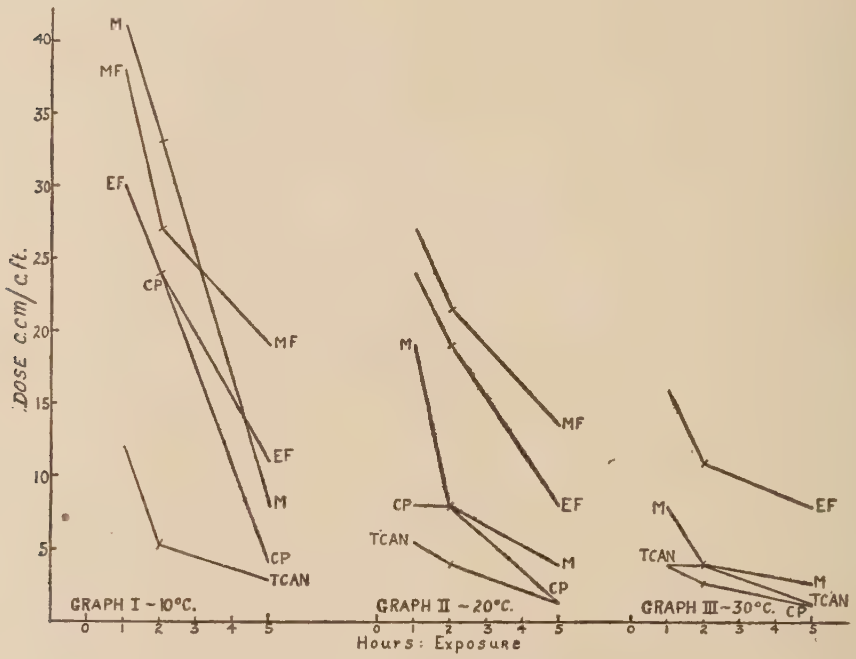

Fig. 1. Dose/time relationship at 10, 20 and 30°C. MF : Methyl formate ; EF : Ethyl formate ; M : Methyl-allyl chloride ; TCAN : Trichloracetonitrile ; CP : Chloropicrin.

Chemical Estimation of Fumigant in Gas Samples from Bins.

As already stated, gas samples were drawn from between the top and bottom layers of blankets in bins containing the minimum effective dose of fumigant. In the one-hour-tests, top and bottom samples were drawn every twenty minutes, while in the two hour tests the samples were drawn 30, 60 and 120 minutes from the commencement. For the purpose of sampling, evacuated 100 cc. all glass flasks were used (Wintringham, 1942).

Methods of Estimation Employed.

All the chlorinated compounds were absorbed in 10 cc. of a 50/50 mixture of dioxan and mono-ethanolamine and then refluxed with a piece of metallic sodium, the chloride being estimated by Volhard's method. This method had been previously worked out for several chlorinated hydrocarbons and methyl-allyl chloride (Wintringham 1942), and as preliminary tests indicated that it gave quantitative results with trichloracetonitrile and chloropicrin, it was utilised for these also.

Methyl and ethyl formate vapour samples were drawn into empty flasks, which were subsequently chilled, and then the appropriate volume (10–20 cc.) of N/20 90 per cent. methyl alcoholic sodium hydroxide free from carbonate was run in. After warming to complete hydrolysis, the solution was titrated with N/10 hydrochloric acid to the nearest 0·02 cc. using phenol phthalein as an indicator (Bryant & Smith, 1936).

Results of Chemical Estimation of Gas Concentrations in Bins.

The essential information obtained by gas sampling the bins as already described is presented in Table II. From the maximum and final concentrations and the time taken to reach the maximum values, an indication of the effective concentration of fumigant prevailing during the course of the treatment can be obtained. When the maximum and final concentration coincide, the concentration of fumigant was still rising slowly at the conclusion of the exposure. As would be expected, the concentration in the lower layers of the bin is usually greatest. In order that these values may be related to the concentrations necessary to give a complete kill of lice eggs, data bearing on this point is set out in column 7 of Table II. The values given are taken from work as yet incomplete and represent the approximate 99 per cent. lethal dose for a *one*-hour exposure at the temperature indicated, the method used being that described in Part I of this paper (David, 1944).

TABLE II.

Results of gas sampling fumigation bins. The doses applied are given in mgm. per. lit. (=*oz. per* 1,000 *cu. ft.*) *and c.cm./cu. ft. The max. and final concentrations as recorded at the top and bottom of the bins are given in mgm. per litre. For explanations of columns* 7 *and* 10 *see text.*

Fumigant	Exposure Conditions				Observed Results						
	Temp. °C.	Time Hrs.	Dose Applied		Time to reach Max. Conc. (Min.)	1 hr. Flasks LD 100 (apprx.) mgm./lit.	Max. Conc. recorded		Final Conc. recorded		% Wt. recovered Max.
			cc./cu. ft.	mgm./lit.			Top	Bottom	Top	Bottom	
Methyl formate ...	10	1	38	1295	<20		272	415	189	285	27
	10	2	27	920	<30		165	185	75	100	19
	20	2	21·5	735	<30	160	203	246	105	119	30
Ethyl formate ...	10	1	24	785	>20	180	190	116	180	102	19
	10	1	30	980	>20		168	260	119	260	22
	10	2	24	785	<30		190	200	105	170	25
	10	5	11	360	<30		58	70	21	34	18
	20	2	19	620	<30	160	140	240	83	148	31
	30	2	11	360	<30	100	175	150	61	73	47
Methyl-allyl chloride	10	2	32·5	1080	>60		152	220	152	220	18
	10	2	32·5	1080	>60		189	162	189	162	18
	20	2	8	260	<30	120	165	98	98	99	50
	20	2	8	260	<30		130	90	79	106	42
	30	2	4	130	<30	100	86	86	79	66	65
Trichloracetonitrile	10	2	3·25	165	>60		37	82	37	82	36
	20	2	2·15	110	>60	80	55	50	55	50	47
	30	2	2·75	140	±60		68	91	54	84	58
Chloropicrin ...	20	2	8	470	>60	40	82	71	82	71	16
	30	2	1·35	79	>60	20	46	47	46	47	58

The first experiment on ethyl formate and the experiments on trichloracetonitrile did not give a complete kill of lice eggs. In all other cases a complete control was recorded and the gas samples confirm this. The samples drawn in the second and third experiments on trichloracetonitrile suggest that an adequate available concentration of fumigant to account for a complete kill occurred, but the biological tests showed that it was not so. No doubt this can be explained by the time lag in reaching maximum concentration and to uneven distribution of fumigant in these small tightly packed bins, but the observation serves to emphasize the importance of running the biological tests in cases of this kind.

In the last column of Table II, values for the maximum percentage weight of fumigant recovered in the air space are recorded. These values were obtained by taking the average of the maximum top and bottom sample concentrations, dividing by the dose applied and expressing as a percentage. If these values are plotted against the temperature at which the test was carried out, approximately straight lines are obtained. The sharp increase in recovery with temperature in the case of methylallyl chloride and chloropicrin is reflected in the decrease in dosage between 10 and 30°C.

Other Small-Scale Methods.

Besides the fumigation tests conducted in bins, a large number of fumigations was carried out in heavy woven sacks. The sacks actually employed were the outer LeLean steam disinfestation containers, one of which was dressed green (probably copper naphthenate canvas preservative) and the other was coated with a brown resinous plastic dressing. As a result of these tests it was reluctantly concluded that the method was unreliable. In an emergency, however, such a container could be used with a 25 per cent. increase in dosage as compared with the bins. That sacks can be used successfully for fumigations has been demonstrated by Evreynova and others (1942) who used sacks composed of several layers of bituminised paper, while Latta & Yeomans (1943) report the use of duck or sateen bags rendered gastight with ethyl cellulose or neoprene. At any rate, the numerous tests carried out serve to emphasise the importance of choosing specially designed materials for fumigation bags, in which case the dose would be similar to that required in a bin.

Another method of fumigation which was investigated, consisted of placing the articles in the middle of a tarpaulin sheet, applying the fumigant and closing over the sheet. This method gave quite good results when tested out with a bundle of twelve blankets, each of which had been previously folded into a square of approximately 3 ft. side. The fumigant was applied to the third and ninth blanket at about 20 per cent. in excess of the rate used for the bin tests.

Large-Scale Practical Fumigation.

When a group of people work or live together, the garments and bedding of all must be treated simultaneously if reinfestation is to be avoided. For this purpose a large fumigation chamber is necessary and under such circumstances speed of operation may be one of the most important considerations. Since such equipment would necessitate the service of trained personnel, there would not be the same objection to a toxic fumigant.

For the purpose of the large scale tests a sectional chamber 6×5×5 ft. high was made from $\frac{3}{8}$th inch plywood. The sides were fitted together with wing nuts. Down the middle of the chamber (in the 6 ft. direction) a sliding partition was arranged; this divided the original chamber into two halves, each of which was closed by a separate door held in position by six wing nuts. Midway along each side of the cabinet a few inches from the top, a port four inches in diameter was cut. Through this a hand could be inserted. When not in use this port was closed by a circular piece of plywood swivelling on a single screw. A sketch of the cabinet is given in fig. 2.

In practice it was found to be most convenient if each half of the chamber was treated as a separate unit, but it is economical to construct and run the two half-chambers side by side. When allowance had been made for the thickness of the walls, each half had a volume of 72 cubic feet and held 120–150 folded blankets. The chamber was loaded in much the same way as the bins when employing safe fumigants, *e.g.*, methyl and ethyl formate and methyl-allyl chloride, but with trichloracetonitrile and chloropicrin injection methods would have to be employed. Only the first method has been investigated. The necessary quantity of fumigant was measured out into a bottle with a sprinkler cap. It is convenient to have the bottle roughly graduated, as this helps to equalise the distribution of the fumigant. Of the total amount of fumigant, three-quarters should be applied as the cabinet is being filled, dividing it equally between the floor and five other applications between the blankets, etc., at intervals of about a foot between, until the last layer has been put on. The surface of the last layer, which may come within about six inches of the top of the cabinet, can be treated through the port after the door has been screwed down, using the remaining quarter of fumigant set aside at the beginning for the purpose. This method has the advantage that only a simple plywood chamber is required, there being no air circulating fans or compressors. In any fairly permanent disinfestation station it would be advantageous to seal the joints between the parts of the chamber with some sealing compound or adhesive tape.

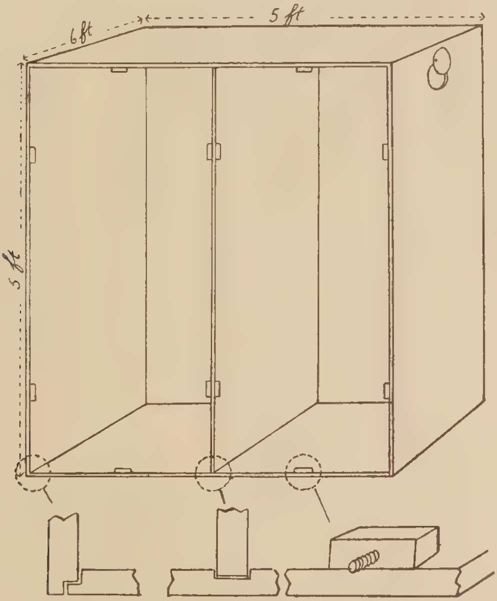

Fig. 2. Diagram of the sectional plywood cabinet used in the large scale tests.

Large-Scale Experimental Fumigation.

A standard procedure was adopted in the experimental fumigations. The filling was always Army blankets, folded and tied together in bundles of ten measuring 24 × 30 × 9 inches and weighing approximately 48 lb. When necessary, the blankets were brought to the temperature of the fumigation by stacking in the chamber with the partition removed and maintaining at the required temperature for 48 hours by means of a fan, heater and thermostat. It was always necessary to arrange fumigations at or above the prevailing temperature. It was most convenient to load and treat all the bundles in the back pile before starting upon the front pile. Muslin bags of lice and eggs were placed at intervals between the blankets and on the edges of the bundles. Sample tubes were also arranged through the sides either into the narrow air space surrounding the bundles or terminating within the blankets.

Dose for Large-Scale Fumigations.

As in the case of the bin fumigations the necessary dose was established by trial and error and was confirmed by several repeat tests. It is interesting to note that near the limiting dose the failures to give complete control occurred in those bags of test insects which had been placed on the edges of the bundles. Chemical samples confirm that the concentration in the small air space surrounding the bundle was less than within the bundles. The fumigant dosage necessary to give complete control of all stages of lice and eggs is set out in Table III.

TABLE III.

Minimum doses of fumigant tested and found to give complete kill of lice and eggs in cabinet fumigations.

Fumigant	Exposure conditions				
	2 Hours			5 Hours	
	10°C.	20°C.	30°C.	10°C.	20°C.
Methyl formate :					
mg./lit.	950	950	—	720	615
c.cm./c.ft.	28	28	—	21	18
Ethyl formate :					
mg./lit.	915	780	—	460	460
c.cm./c.ft.	28	24	—	14	14
Methyl-allyl chloride :					
mg./lit.	—	390	345	345	245
c.cm./c.ft.	—	12	10·5	10·5	7·5

Chemical Estimation of Fumigant in Gas Samples from Cabinet.

As already explained, provision was made in the experimental cabinet for gas samples to be taken. Four sampling tubes were inserted, two near the top, one in the blanket bundle and one in the surrounding air space, the other two similarly near the bottom. Samples were drawn after half an hour, one hour, and then at longer intervals according to the duration of the test. The method of analysis used has already been described.

The results obtained are set out in a condensed form in Table III, and Graphs IV and V (fig. 3) also show typical results for ethyl formate and methyl-allyl chloride.

It will be noted that the gas concentration within the blanket bundles, forty single layers of blankets from the point of application of the fumigant (*i.e.* in the middle of the bundles), was always higher than in the air space. This confirms the result already given that failures to obtain complete kill near the minimum effective dose always occurred in the bags exposed on the edge of the piles. The rate of fall of fumigant concentration could be reduced by sealing the joints in the cabinet as already suggested. This would be especially advisable if the cabinet were used out of doors since it has been shown that in the face of a 30 m.p.h. wind, air passes even through a well made brick wall thirteen inches thick (Simmons *et al.* 1935). A more rapid fall in concentration of fumigant in rooms on windy days has been recorded by Busvine (1943).

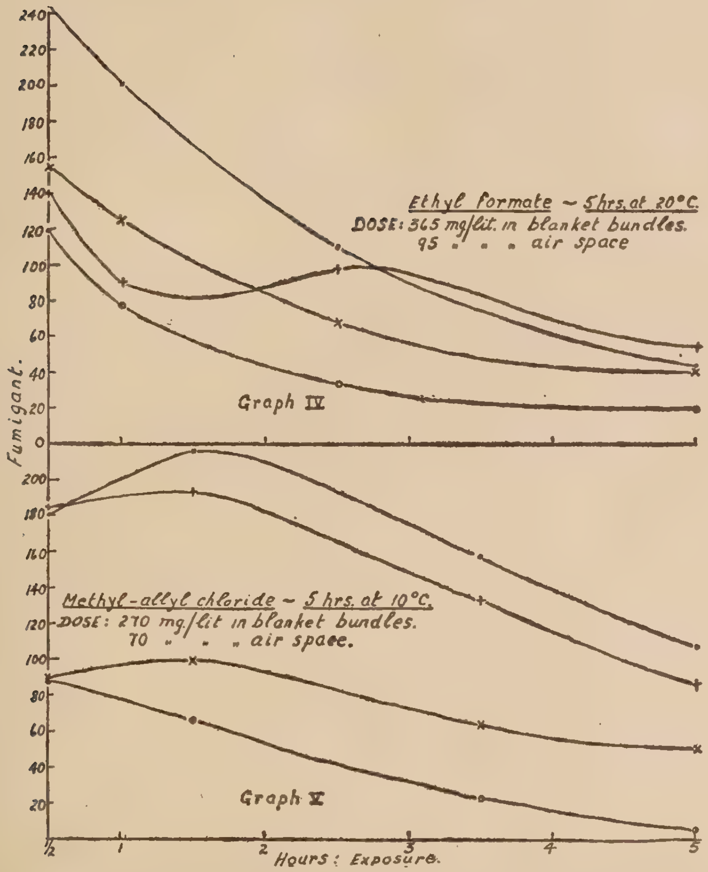

Fig. 3. Fumigation results for ethyl formate and methyl-allyl chloride. ● = concentration in lower blanket bundle. + = concentration in upper blanket bundle. × = concentration in lower air space. o = concentration in upper air space.

Review of the Large-Scale Fumigation Method.

The disadvantages of the method as developed are the comparatively long exposures (2 or 5 hours) and the large volume of fumigant necessary. The advantages lie in the simplicity of the chamber and the quantity of material that can be treated in a small space. Thus 120–150 blankets (7·7–10 lb. per cu. ft.) can be loaded into 72 cubic ft. of space, whereas for hot air disinfestation of 150 blankets, about 625 cu. ft. would be required according to one method. This gives a loading of only 1·2 lb. cu. ft.

The long exposure necessary is partly dependent upon the toxicity of the fumigants to lice, which, in the case of the formates and methyl-allyl chloride is not high compared with hydrogen cyanide, and partly upon the difficulty of penetrating such a densely packed mass. Unless carried to extremes, however, little advantage would be gained by separating the blankets, and it would be less economical in fumigant to dose a relatively large space only lightly loaded with blankets. In this method penetration depends upon applying the fumigant between the blankets; satisfactory results cannot be obtained by dosing the air space. With an injection method, which would have to be employed with a noxious fumigant, good results could be obtained with an adequate number of injections. A few experiments made along these lines were promising but the method was not fully developed.

TABLE IV.

Results of gas sampling fumigation cabinet. The doses applied are given in mgm. per litre (=oz. per 1,000 cu. ft.) and c.c. per cu. ft. The maximum and final concentrations are given in mgm. per litre.

Fumigant	Exposure Conditions				Observed Results				
	Temp. °C.	Time Hrs.	Dose applied		Time to reach max. concent. min.	Max. conc. mg./lit.		Final conc. mg./lit.	
			c.cm./c.ft.	mg./lit.		Bundles	Air	Bundles	Air
Methyl formate...	10	2·5	28	950	<30	—	215	—	70
	10	2	28	950	<30	—	196	—	62
	10	2	28	950	<30	261	178	129	74
Ethyl formate...	10	2	28	915	<30	—	188	—	133
	10	2	28	915	<30	—	183	—	99
	10	5	28	915	<30	195	197	73	58
	20	2	28	915	<30	276	206	176	100
	20	5	14	460	<30	200	136	51	30
Methyl-allyl chloride	10	5	10·5	345	>60	210	89	98	28
	20	2	14	460	± 60	245	186	189	82
	20	5	7	230	± 60	115	81	78	32

The Choice of Fumigant.

The properties of the fumigants dealt with have been fully described (David, 1944), and references have been given to the relevant literature on physical and chemical properties, and toxicity to man. By referring to this information, the most suitable fumigant to use in any particular set of circumstances can be more easily determined. Briefly it may be said that for prevailing temperatures below 20°C., either of the formates or trichloracetonitrile should be chosen, at about 20°C. or above, all the fumigants are suitable, except that methyl formate (B.P. 31·5°C.) is too volatile to use at much above 25°C.

With unskilled operators toxicity is a most important consideration. An examination of the literature leads to the conclusion that the vapours of all organic liquids in sufficient quantity are injurious or even dangerous. For example petrol vapour is quite toxic at 1–2 per cent. vol. *Methyl* and *ethyl formates* may be regarded as relatively safe, and the literature gives no records of fatal cases in industry resulting from the use of these. They are, however, inflammable and fires must be guarded against. Gas masks are unnecessary for bin fumigations with the formates, but advisable for the large scale cabinet method. *Ethylene dichloride* is one of the least injurious of the chlorinated hydrocarbons and is not known to give rise to any chronic symptoms. So far as is known, *methyl-allyl chloride* does not cause the chronic symptoms associated with certain chlorohydrocarbons such as carbon tetrachloride. Its toxicity has, however, been described as " approximately equal to carbon disulphide " (Briejèr, 1939 b). Another series of experiments confirms this (Lacquer, 1938). In practice bin fumigations can be carried out without the use of a mask, which might, however, be advisable in the case of full time operators. In the large scale fumigations a mask is necessary. Both *trichloracetonitrile* and *chloropicrin* demand efficient gas masks and general care in the handling of dangerous chemicals.

Effects of Fumigants on Clothing.

So far as is known under the conditions of the tests, no damage is caused to cotton or woollen clothing. A variety of experiments was carried out in which variously dyed fabrics were exposed to the fumigants for lengthy periods. No cases of fading were discovered. In addition, tests were made in order to ascertain whether it was likely that the formates which hydrolyse slowly in the presence of moisture would give rise to sufficient formic acid to damage cotton fabric. As a result of these tests in which the conditions were much more severe than any which would occur in practice, it was concluded that no damage was likely to result.

Acknowledgments.

I am indebted to Professor P. A. Buxton, F.R.S., under whose direction the work has been carried out. In addition the following firms have supplied materials and technical information. Messrs. Imperial Chemical Industries, Technical Products, Drake Law Laboratories, Boake and Roberts, Phantomyst, Associated Fumigators and London Fumigators. The blankets and LeLean sacks were kindly lent by the Command Ordnance Depot. The Medical Research Council was responsible for the grant under which the work was carried out. Finally, I should like to thank Mr. A. Harvey for his assistance throughout the work.

Summary.

The paper describes small and large scale methods of fumigation which have been worked out for six fumigants. The conditions under which complete control of body lice and their eggs may be obtained are set out, and the relative uses of the two methods and the various fumigants are described. Four of the materials tested, methyl formate, ethyl formate, ethylene dichloride and methyl-allyl chloride are comparatively safe and pleasant to handle, but they sometimes demand rather heavy dosages of fumigant or long exposures, especially at temperatures below 20°C. Chloropicrin and trichloracetonitrile on the other hand have strongly irritating properties, but their toxicity to lice is also much greater. The methods have the advantage that some are very safe and all are simple, demanding no elaborate technique or apparatus.

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SOME RECORDS OF SIMULIIDAE IN ABYSSINIA AND BRITISH SOMALILAND.

By G. R. Cunningham van Someren.

During the campaign in Abyssinia and British Somaliland, the writer was able to collect a few Simuliid flies during the course of mosquito surveys. All the specimens collected were submitted to the late E. G. Gibbins of Uganda, who kindly determined them, and at his suggestion I record the four species found, as it is believed that these constitute the first records of these species from the two territories.

Abyssinia.

Three species are recorded: *Simulium elgonensis*, Gibbins, *S. dentulosum*, Roubaud, and *S. brachium*, Gibbins.

Simulium elgonensis, Gibbins.

20 ♂♂♀♀ bred from isolated pupa, x.1941. Mojjio, Centr. Abyssinia.

The species was found at Mojjio, a small town some 45 miles south of Addis Ababa on the railway line to Dire Daua, at 5,800 ft. Hitherto the species was only known from Uganda Protectorate, the type locality being Mount Elgon. It is of interest to note that De Meillon (1943) has recently recorded this species from Portuguese East Africa. Larvae and pupae were located in numbers in the Mojjio river just outside the town in the vicinity of cascades, falls and the spill over a dam wall. No larvae were located in the quiet water. Adults were numerous in the late afternoon but were not attracted to man. A few larvae and a single pupal pelt were found attached to stones in a small fast flowing stream near Dalle, circa 5,700 ft. October 1941. Dalle is on the South Road from Addis Ababa to the Kenya border near Lakes Margherita and Auasa, Central Abyssinia.

Simulium brachium, Gibbins.

5 ♂♂♀♀ bred from isolated pupae; also wild caught adults from Gimma, 5,800 ft., xi.1941.

Gibbins described this species from material collected in Uganda at Bumboi, Mount Nkokonjeru at 6,000 ft. Specimens were again obtained at Bwamba at 2,500 ft.

The specimens taken at Gimma were bred from pupae recovered from a small well-shaded forest stream where the larvae were found on stones and boulders. During November the stream was little more than a trickle. The larvae and pupae were associated with *S. dentulosum*, but favoured the tops and upper half of the sides of the stones, whereas those of *S. dentulosum* were found on the lower portions. A few adults were captured in the vicinity of the stream, but they did not attempt to bite or cause annoyance.

Simulium dentulosum, Roubaud.

Larvae and pupae were found in association with *S. brachium* in a well-shaded forest stream at Gimma, 5,800 ft., xi.1941, and a number of adults were bred from pupae.

Thirty-one adults were captured on the rivers Chitto and Aueta in Gimma between 5.30 and 6 p.m. during which period they appeared in the greatest numbers. They were attracted to man but were not actually observed to bite and draw blood ; they were, however, annoying in that they crawled over one's hands, face and back of one's knees. No larvae or pupae were located in these rivers, but this was probably due to the fact that there had been heavy rain previously and the streams were both muddy and rather full.

Gibbins suggests that this species probably feeds on birds or small mammals with more delicate skins than man.

British Somaliland.

Only one species was found in this territory and only in one stream.

Simulium ruficorne, Macquart.

A widely distributed species occurring in Africa generally, the Mediterannean region and Palestine but apparently not previously recorded from British Somaliland.

Larvae and pupae were recovered from the tug at Mandera Camp, a camp some 60 miles inland from Berbera, circa 3,140 ft., i.1942. A few adults were bred.

The breeding-place is interesting as tugs are more or less sand rivers with small patches of seepage where a rock barrier occurs across the course of the river. Heavy flooding takes place only after rain in the watershed. These seepages may be only a few feet in extent or up to a mile of seepage stream, but at no time during the dry season is the water more than a few inches in depth. At Mandera the water was warm and smelt sulphurous. The larvae were nearly all attached to the filaments of algae (*Spirogyra*), but pupae were usually on small stones.

In some instances larvae were found in small pools and footprints, where there was no obvious flow of water, and this suggested the possibility of breeding them out in test tubes. The larvae pupated successfully, and adult flies were obtained with suprising ease. The pupal period occupied a week to nine days. Few adults were noted in the vicinity of the breeding-place, and there was no evidence that they were attracted to man or attempted to bite.

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DESTRUCTION OF LICE IN CLOTHING BY HOT AND COLD AIR.

By J. R. Busvine, B.Sc., Ph.D.,

Entomologist, Ministry of Health.

Introduction.

The most suitable methods of disinfesting clothing and bedding depend upon circumstances, such as the extent and importance of the pest infestation, the numbers to be treated and the facilities available. This paper describes investigations of heat and cold for killing lice which were undertaken with an eye to very different situations, *viz.*, the heat treatment of bedding in London air-raid shelters and the possible use of winter cold in Eastern Europe during post-war relief. Nevertheless, the problems have one thing in common; the inherent difficulty of heat transference through clothing and bedding.

Various articles of clothing and bedding must vary greatly in heat insulation so that it is difficult to generalise. As a rough standard, ordinary army blankets (also used in civil defence posts) were adopted and were used in both experiments with heat and with cold. The thermal insulation value of one typical blanket was very kindly determined for me by the Wool Industries Research Association at the request of Dr. T. Bedford. The measurements made are given in comparison with an all-wool blanket and with a poor quality substitute. It will be seen that the sample was intermediate between them.

Blanket	Weight oz./sq. yd.	Thickness at 5 gm/cm^2 pressure	Thermal Insulation Value	Approx. Thermal Conductivity
All wool...	13·3	·228 cm.	40%	8×10^5cal/cm/sec/°C.
Sample	17·2	·286 cm.	32%	14 ,, ,,
70% Waste Hessian ... 30% Shoddy	15·5	·237 cm.	22·5%	20 ,, ,,

DESTRUCTION OF LICE BY HOT AIR.

Laboratory Data.

The precise limits of resistance of lice and eggs to high temperature were defined by Buxton (1940) and are set out in Table I in comparison with data for certain other parasites.

The louse eggs used by Buxton were from one to five days old, since older eggs were less resistant. These young eggs appear to be rather more difficult to kill by short exposures to high temperature than the other human parasites. Accordingly they make a good test subject, for if louse eggs are destroyed, it can be assumed that other common vermin will be killed.

TABLE I.

Resistance to high temperature of louse, bug, itch mite and a species of flea.

Exposure (Mins.)	Lethal Temperature (°C.)					
	Pediculus		*Cimex*		*Sarcoptes*	*Xenopsylla*
	Egg	Adult	Egg	Adult	Adult	Adult
5	53·5	51·5	—	—	—	—
10	52	50	—	—	49	—
30	50	47	—	—	47·5	—
60	—	46	45	44	—	39·5
Authors	Buxton (1940)		Mellanby (1935)		Mellanby and others (1942)	Mellanby (1932)

Small Scale Trials.

The object of these experiments was to measure the penetration of heat into a bundle of blankets put into hot air at a constant temperature.

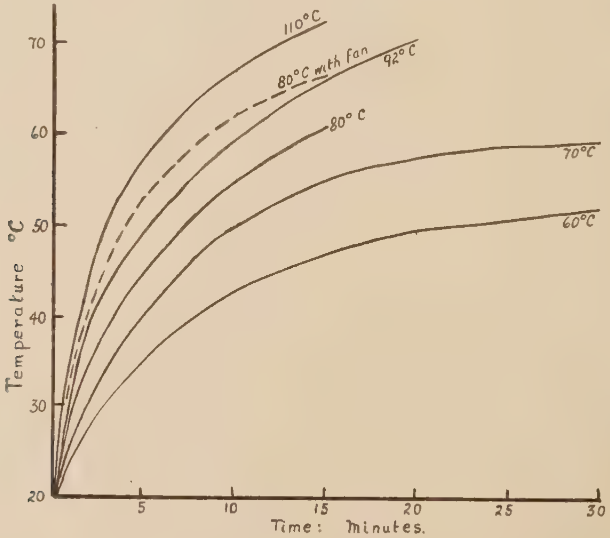

Fig. 1. Records of the thermocouples under one layer of blanket for various oven temperatures.

A piece of blanket material 1 metre square was folded four times into a wad of 16 thicknesses, and thermocouples were inserted between the top three layers. This bundle was rapidly introduced into a water-jacketed oven about 2 ft. long and 1½ ft. internal diameter. (Measurements of the free air temperature proved that this operation caused only a slight loss of heat which was soon made good.) It was assumed that the heat penetrating the top three layers came exclusively by conduction from the hot air and by radiation. Conduction through the bottom 13 layers was neglected. The temperature of the blanket before the experiment (*i.e.* the room temperature) was approximately 20°C. throughout.

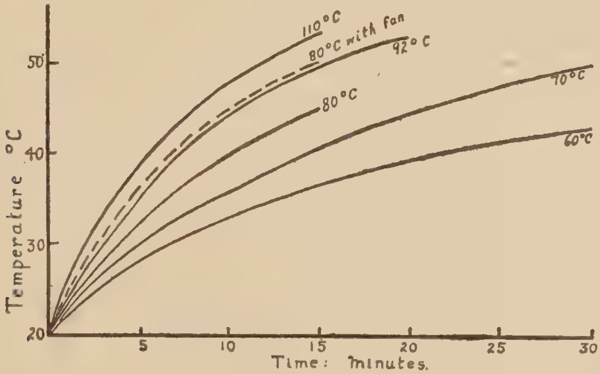

Fig. 2. Records of the thermocouples under three layers of blanket for various oven temperatures.

The records of the thermocouples under one and three layers of blanket are shown in figs. 1 and 2 for various oven temperatures. All the curves fall off logarithmically as the temperature in the blanket approaches that of the hot air. By plotting the curves against a logarithmic time scale, straight lines are obtained which can be fitted more accurately. From such lines have been calculated the times necessary to reach a rapidly lethal temperature (54°C.) under one or three layers. Adding on five minutes for a fatal exposure, the following times were estimated :—

TABLE II.

Exposures to kill lice under blankets in still hot air.

Air temperature	Lethal exposure when protected by blanket	
	1 layer	3 layers
110°C.	9½ minutes	20 minutes
92°C.	12 ,,	25 ,,
80°C.	14 ,,	35 ,,
70°C.	20 ,,	58 ,,
60°C.	50 ,,	115 ,,
80°C. with fan	11 minutes	25 minutes

In one test an electric fan was put in the oven close to the blanket wad. The turbulence of the air greatly accelerated the heat transference and reduced the necessary exposure by about 25 per cent.

Field Trials.

A. *Heated rooms without forced draught.*

With the co-operation of Dr. Macmillan, Dr. Standring and Mr. Sumner, trials were made in two hot air chambers in the Borough of Woolwich. One chamber was the hottest room of the Turkish baths at Plumstead which can be maintained at a temperature between 70° and 80°C. This room is heated by a slow (imperceptible) current of air which passes round furnace flues, enters the room by openings round the base of the walls and returns from a port near the ceiling to be re-heated. The other chamber was a specially built disinfestation room at Sherrard Road Cleansing Station, lined with cork and heated by five electro-vapour 10 KW heaters, controlled by a thermostat. The capacity of the Plumstead chamber was approximately 500 cu. ft. and that of the Sherrard Road one was 250 cu. ft.; both rooms were about 9 ft. high.

In each test a folded blanket was placed on the floor, another at two feet and a third at six feet from the floor. Lice and eggs in muslin bags were placed under one and three layers of the blankets and the air temperature at 4–5 feet was read at intervals. After the exposure, the bags of insects were removed, and a few hours later the lice were put into breeding boxes on the leg and the eggs into an incubator at 30°C. The kills of lice were determined within two days and the egg mortality when the controls had hatched.

The results of four experiments are summarised in Table III. Trial No. 3 at Sherrard Road was completely ineffective. The other trials were moderately successful at 6 ft.; but even there only a partial kill of eggs was produced under three layers.

The poor results at two feet from the floor and below were due to layering of the hot air. In test 1, where the temperature of 74°C. was recorded at 5 feet, the temperature of the floor was only 40°C. rising to 50°C. a few inches up.

Owing to this poor distribution of heat, hot air chambers are rather unreliable. If they are used, the following conditions must be fulfilled :—

Only that part of the chamber which can give a free air temperature of 70°C. when fully loaded may be used. The temperature must be maintained at this level for an hour's exposure.

TABLE III.

Results of tests in heated chambers.

Site	Trial No.	Exposure	Average Temp. (4 or 5 feet)	Under blanket	Percentage kill of test insects					
					At Floor		At 2 feet		At 6 feet	
					Lice	Eggs	Lice	Eggs	Lice	Eggs
Plumstead ...	1	½ hr.	74°C.	1 layer	100	89	—	—	100	100
				3 ,,	0	11	0	0	100	94
,,	2	¾ hr.	70°C.	1 ,,	100	100	100	100	100	100
				3 ,,	0	0	0	0	100	20
Sherrard Road	3	½ hr.	62°C.	1 ,,	0	0	—	—	0	0
				3 ,,	17	0	0	0	0	8
,,	4	1 hr.	66°C.	1 ,,	0	0	0	0	100	100
				3 ,,	0	8	0	0	100	19

B. *A Trial of the "Millbank" Disinfestor.*

In view of the far greater efficiency of moving hot air, the Army adopted early in the War a portable disinfestor in which the air is circulated by a forced draught. This apparatus, which is known as the "Millbank" Disinfestor, is also used by some civilian authorities (Borough Health Departments, etc.) for treating bedding bundles of air raid shelterers.

During a routine disinfestation in the Borough of Marylebone, the opportunity was taken to test the performance of the apparatus. The disinfestor was working in the open with an outside air temperature of 10°C. An assortment of rugs, bedding and clothing was being treated. Twenty test batches of louse eggs were placed at various points among the bedding and three thermocouples were also inserted as follows :—

A. Exposed, in the centre of the chamber

B. Under two blankets, in the centre of the chamber

C. Under two blankets, near the loading entrance

All three were about half way between floor and ceiling.

The hot air was circulated for half an hour and then cut off ; the loading curtains were opened and the interior allowed to cool for 15 minutes before unloading and collection of the test louse eggs.

The temperatures (°C.) recorded during the run were as follows :—

	Minutes from start of hot air circulation									
	5	10	15	20	25	30		35	40	45
A	46	65	77	88	95	101	Heat	90	56	37
B	38	56	67	77	83	88	cut	86	64	43
C	20	37	48	52	54	55	off	54	42	36

Position C was chosen as being the most difficult part of the chamber to heat and, indeed, the temperature beneath the blankets there was 30°C. lower than at B. Nevertheless, the louse eggs at C were killed and in all other batches except three. These three were protected respectively by (*a*) a folded pillow, (*b*) a folded palliasse, (*c*) a thick folded eiderdown. (The folding was the result of hanging the bedding over rods so that two halves hung down side by side.)

The treatment successfully killed all lice eggs whether near the top or bottom of the chamber and at various points except for these three inaccessible points. It appears that the disinfestor is much more efficient than hot air chambers without air circulation, and that it can be relied upon to disinfest clothes and blankets (but not pillows or mattresses) with a half-hour exposure.

C. *A Hot-air Disinfestor attached to an Air-raid Shelter.*

The Civil Defence authorities, no less than the Army, are aware of the convenience of hot air disinfestation. For the treatment of bedding in large air raid shelters, particularly the deep shelters, a new type of disinfestor has been developed by officers of the Ministry of Home Security and the consulting engineers responsible for constructing the deep shelters. Full details will be published elsewhere but it may be briefly described as a gas-heated chamber with a circulating hot air system. It consists of a tunnel 30 feet long and about 6 ft. by 6 ft. in cross section, with doors at each end. The bedding to be disinfested is placed over rods carried on cradles which hang from an endless overhead rail running right through the chamber and completing the circuit outside.

There are ten cradles, of which five can be disinfested at a time, allowing the remainder to be unloaded and reloaded.

The temperature can be maintained steadily at any temperature up to 260°F. (127°C.).

When a set of loaded cradles have been run in, the temperature naturally falls; but, unless the materials are very damp and cold, the regulated temperature is regained in quite a short time (about 5–10 minutes).

Experimental.

The first disinfestor of this type was completed in 1943, and tested during some cold weather in November, *i.e.* under unfavourable conditions.

Small pieces of tape bearing body louse eggs and identification numbers were pinned to various parts of the bedding before exposure. Afterwards, the test eggs were collected and incubated at 30°C. to determine the percentage hatch. Among the control eggs 80–90 per cent. hatched.

Results.

In all tests the exposure was for 20 minutes after the required temperature had been reached.

Test No. 1.

Average temperature 220°*F.* (105°*C.*) (*reached in about* 5 *minutes from entry of the cradles*).

Cradle No.	Position	Percentage hatch of eggs
1	In mattress fold	80
1	In blanket fold	0
1	In blanket fold	0
3	In mattress fold	79
3	In mattress bottom	0
3	In blanket fold	0
4	In mattress fold	67
4	In blanket fold	0
5	In blanket fold	0
5	In mattress fold	43

Test No. 2.

Average temperature 260°*F.* (127°*C.*) (*reached within* 8 *minutes*).

Cradle No.	Position	Percentage hatch of eggs
1	Mattress	52
1	Blankets	0
1	Blankets	0
2	Blankets	0
2	Blankets	0
3	Mattress	50
3	Blankets	0
3	Mattress (bottom)	0

In these first two trials the results were quite definite: the only failures were louse eggs secreted between the two touching sides of mattresses hanging over rails. Accordingly in the next two trials the mattresses were each hung over two rails about 9 inches apart and inside the arch so formed, two blankets were hung on rods at a slightly lower level. This arrangement enabled the hot air to penetrate to all surfaces of the mattresses. Pillows were hung on hooks from one end of each mattress.

Test No. 3.

Average temperature 240°*F.* (115°*C.*) (*reached in about* 10 *minutes*).

Cradle No.	Position	Percentage of eggs
1	In blanket under arch (a)	0
1	In blanket under arch (a)	0
1	In blanket under arch (b)	0
1	In blanket under arch (b)	0
1	On mattress under arch (a)	0
1	On mattress under arch (b)	0
3	In eiderdown	0
3	In blankets...	0
3	In eiderdown (bottom) ...	0

Test No. 4.

Average temperature 220°*F.* (105°*C.*) (*reached in* 5 *minutes*).

Cradle No.	Position	Percentage of eggs
5	In blankets under arch (a)	0
5	In blankets under arch (a)	0
5	In mattress under arch (a)	0
5	In blankets under arch (b)	0
5	In blankets under arch (b)	0
5	In mattress under arch (b)	0
5	In mattress under arch (b)	0
5	In thick wad of blankets	75
5	In blankets...	0

These two trials prove the adequacy of this method of suspending the bedding. The only failure was in a thick wad of blankets amounting to about five or six thicknesses on either side of the eggs.

Conclusions.

It has been shown that the disinfestor is capable of disinfesting bedding with 20 minutes exposure to an air temperature of 220°F. or over, *provided* that no great thickness of material protects the vermin. To prevent this, mattresses or palliasses must be hung so that their entire surface is exposed to the circulating hot air. Blankets should be hung in such a way that there is nowhere more than two thicknesses protection from the hot air.

DESTRUCTION OF LICE BY COLD AIR.

There exist only a few scattered data on the resistance of lice to low temperatures (Chung, 1937), but it is clear that lice are not very easily killed by cold and that artificial chilling is not a practical measure. However, typhus epidemics are quite liable to occur in winter in parts of the world where the winter temperatures are exceedingly low, and it is important to know whether these natural low temperatures can be relied upon to disinfest clothing in a reasonably short time.

Some of these areas may become devastated or famine stricken as a result of the present war, and, in post-war relief, it would be difficult to send insecticides and equipment to them since all transport would be required for food (see Mackenzie, 1942). In such cases, delousing measures not requiring special apparatus would be especially valuable.

Laboratory Experiments.

Body lice and their eggs were taken from pill box cultures which were kept against the skin of the leg during the day. They were exposed to cold air in small cages of black voile with very little specific heat. From 8 to 20 lice and 25 to 100 eggs were used for each exposure.

TABLE IV.

Resistance of lice and their eggs to low temperatures. The egg mortalities have been corrected for control deaths.

Exposure in hours	Percentage killed at different temperatures									
	−20°C.		−17·5°C.		−15°C.		−10°C.		−5°C.	
	Lice	Eggs	Lice	Eggs	Lice	Eggs	Lice	Eggs	Lice	Eggs
¼	11	23								
½	100	23	75							
¾	100	46	94							
1		50	100	17	88					
2		93	100	44	100					
4		100		82	100	64	30			
5		100		100		79	45			
7½						80	100	5	0	30
10						100	100	14		
12									25	27
15									59	
20								82	100	
24								100	100	
46										44
53										73
64										99
71										100

It was considered that a very violent change of temperature would not be likely to occur in a garment under practical conditions and, since such a sudden change might be especially harmful, the lice were chilled in two stages. From the leg (30°C.) they were sorted and placed in the cages at room temperature (about 10 minutes at 20°C.). Then the cages were placed in a refrigerator for 20 minutes at about 0°C. Finally they were exposed to the test temperature. Preliminary tests showed that recovery from this gradual chilling was more likely than from an abrupt transference.

The low temperatures required were obtained in the ice box of an ordinary refrigerator fitted with a thermostat which worked down to -20°C. The temperature fluctuated considerably as the cooling system cut on and off, but this was damped by a vacuum flask. Inside the vacuum flask the variation was not more than ±1°C.

Experiments with eggs up to three days old and eggs older than that indicated that the younger eggs were more susceptible. But the difference was not great and eggs of all ages were pooled for the general experiments.

Table IV shows the exposures which are needed to kill lice and their eggs. These results can best be shown graphically by converting to time exposure to a logarithmic scale when it will be seen that the logarithm of the exposure is a linear function of the lethal low temperature (Figs. 3, 4).

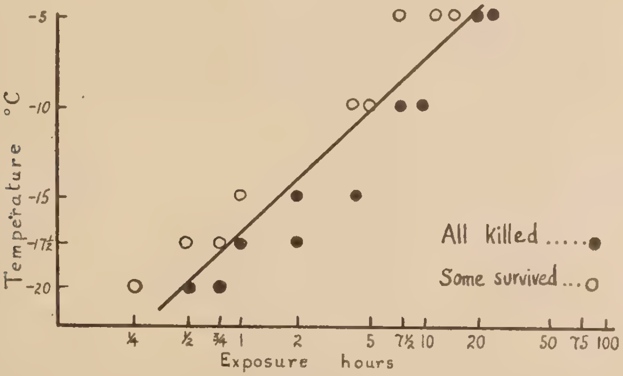

Fig. 3. Resistance of lice and their eggs to low temperatures.

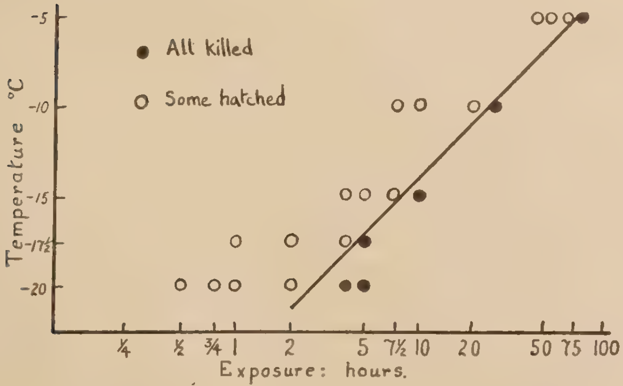

Fig. 4. Resistance of lice and their eggs to low temperatures.

Practical Trials.

Having found the low temperatures lethal to exposed lice and eggs, it was necessary to determine whether they can be killed by reasonably short exposures (less than 12 hours) when protected by a thick garment. For these practical tests, the use of a cold chamber was kindly allowed by the Director of the Road Research Station.

Lice and eggs were secreted in (*a*) a lined musquash fur coat ; (*b*) the folds of a woollen blanket ; both at room temperature before the experiment. (It was found that one thickness of the coat gave about the same protection as three layers of blanket.) The rate of fall in temperature was observed by thermocouples and a galvanometer.

Results.

In two trials in which the temperatures were recorded, the cooling proceeded as follows :—

Air temperature	Temperature inside coat or 3 folds of blanket at various times				
	½ hr.	1 hr.	2 hrs.	3 hrs.	5 hrs.
−15°C.	0°C.	−5·5°C.	−11°C.	−13°C.	−14·5°C.
−20°C.	−2°C.	−8°C.	−14°C.	−17°C.	−19·5°C.

The effect on the lice and eggs is shown in Table V.

TABLE V.

Kill of protected lice and eggs by low temperatures. (Egg mortalities adjusted for control deaths.)

Air temperature	Exposure	Percentage killed					
		2½ hrs.		5 hrs.		12 hrs.	
		Adults	Eggs	Adults	Eggs	Adults	Eggs
−15°C.	In coat	0	0	100	25	100	71
	In blanket (1 layer)	100	0	—	—	—	—
	In blanket (3 layers)	70	0	100	41	—	—
−20°C.	In coat	90	23	100	100	—	100
	In blanket (1 layer)	—	80	—	100	—	—
	In blanket (3 layers)	100	0	100	90	—	—

The results show that a complete kill of adult lice is fairly easy to attain even when they are protected by a thick garment : there were no survivals after 5 hours at −15°C. The eggs, being more resistant, survived 5 hours at −20°C. and 24 hours at −15°C. But their destruction might be a matter of rather less importance than the adults because the typhus rickettsia cannot be transmitted through them.

As a general conclusion one could be sure of delousing all types of garments (at least from adult lice) by exposing them overnight to a temperature of minus 15°C. or lower.

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THE UTILISATION OF METABOLIC WATER IN INSECTS.

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It has often been suggested that insects that develop on substances with a low water content, such as flour, grain, fishmeal or wool, obtain their necessary water from the products of food combustion. Recently we have shown for a number of insects, which normally live on flour and other dried food, that growth is faster at high than at low humidities. Some of these insects grew quite well at 20 per cent. relative humidity (R.H.) on flour with a water content of only 7 per cent., and one, *Ephestia kuehniella*, developed even at about 1 per cent. R.H. on flour containing about 1 per cent. of water (Fraenkel & Blewett, 1943 a). The water content of the insects concerned is 60–70 per cent. It is difficult to see how a growing larva can accumulate such quantities of water from such dry foods unless it makes use of the water which is derived from the oxidation of food. This explanation would account for the slowness of growth at low humidities, because food which is used for providing water cannot be used for growth. The insect would, then, be expected to eat more food per weight of body substance produced at low than at high humidities. The estimation of the ratio, dry weight of food eaten/dry weight of body substance produced, at different humidities is the principal subject of this paper.

Methods.

All the experiments, except one with *Ephestia kuehniella*, were carried out at 25°C. in desiccators containing suitable solutions of KOH to maintain the desired humidities (according to the tables of Buxton, 1931). For *E. kuehniella* a humidity of less than 1 per cent. was produced over P_2O_5. At the lower humidities the humidity tended to rise slowly during an experiment. The humidities and water contents of foods given in the tables are those measured at the end of experiments, and they may, at 20 per cent. R.H., have been slightly lower at the beginning of the tests. The methods of breeding the insects and assessing the results are described elsewhere (Fraenkel & Blewett, 1943 a, b, Fraenkel, Reid & Blewett, 1941). In all the tests first stage larvae were introduced on a known quantity of food. As soon as the larvae had pupated, wet and dry weights of pupae and of residue of food were determined. The dry weights of pupae and food were determined with *Tribolium* and *Ephestia* by drying at 100°C. With *Dermestes* the water contents were determined at 70°C., because fructose quickly decomposes at higher temperatures. The following data were thus obtained: duration of larval period, dry weight of food eaten, water content of food and of pupa, and the " net utilisation " of the food, *i.e.* the ratio food eaten/weight produced.

Experiments.

Tribolium confusum.

Two relative humidities were used, 70 and 20 per cent. At each humidity two batches of 100 first stage larvae were placed on 4 g. of patent flour containing 5 per cent. yeast. This food was chosen because it was originally intended to separate at the end of the experiment the " frass " from the remainder of the food. This, however, proved impracticable. The newly formed pupae were removed daily and weighed alive, and the dry weight of the whole batch was determined later. The results are given in Table I. It is seen that there is very little difference in the number of pupae formed at the two humidities, and in their dry and wet weight. But at the lower humidity, the larvae eat a great deal more food. For every milligram dry weight of pupa produced, 5·1 and 5·2 mg. of food (dry weight) were consumed at 70 per cent. R.H., and 7·4 and 7·0 mg. at 20 per cent. R.H. The moisture contents of the food at 70 per cent. R.H. were 13·83 and 13·25, and at 20 per cent. 7·36 and 7·44 per cent.

TABLE I.

Tribolium confusum *grown at* 70% *and* 20% *Relative Humidity.*

Relative humidity	Number of pupae	Moisture content of food %	Pupa			Dry weight of food eaten mg.	$\frac{\text{Dry weight of food eaten}}{\text{Dry weight of pupa}}$
			Wet weight mg.	Dry weight mg.	Water content mg.		
70%	98	13·83	253·5	108	57·4	562	5·20
70%	98	13·25	265·5	116	56·3	594·5	5·13
Average per pupa ...		13·54	2·65	1·14	56·8	5·90	5·17
20%	91	7·36	247·5	105·5	57·4	783·4	7·44
20%	98	7·44	252	109	56·7	766·4	7·03
Average per pupa ...		7·40	2·64	1·13	57·0	8·2	7·25

Ephestia kuehniella at 25°C.

The food was wholemeal flour. The larvae were reared in single cultures, each first stage larva being started on 200 mg. at 70 and 20 per cent. R.H. and 300 mg. at 1 per cent. R.H. At the end of the larval period there remained in the tube an inseparable mixture of flour, " frass " and webbings. The amount of food eaten was calculated by subtracting the weight of the residue from the original weight. The results are tabulated in Table II, and the averages with standard deviations and tests for significance are summarised in Table V. It is seen that the larval period lengthens with decreasing humidities, which has been demonstrated before by Ahmad (1936) and ourselves (1943 a). Dry weight and wet weight of the pupae decrease with decreasing humidity. The differences between dry weights at 70 and 20 per cent. are highly, and at 20 and 1 per cent. perhaps just, significant. The moisture content of the pupae is lower at lower humidities, as was to be expected, and the differences are statistically significant. The absolute differences are, however, surprisingly small, considering the vast difference in water content of the foods. More food is eaten per larva as the humidity decreases, and this is most strikingly shown in the figure for " net utilisation." 1 mg. dry substance of pupa is produced from 6·3 mg. of dry food at 70 per cent., from nearly 9 mg. at 20 per cent., and from 12·7 mg. at 1 per cent. R.H. These differences are highly significant.

Ephestia kuehniella at 20°C.

For reasons which will be discussed more fully later in this paper, it was desirable to know whether the primary cause of the increase in the " net utilisation " figure at lower humidities was the lengthening of the larval period. *E. kuehniella* was grown at 70 per cent. R.H. and at a temperature of about 20°C. There was some fluctuation

TABLE II.

Ephestia kuehniella *grown at* 70%, 20% *and* 0% *Relative Humidity. Temperature* 25°C.

Relative humidity	Moisture content of food %	Larval period days	Wet weight of pupa mg.	Dry weight of pupa mg.	Water content of pupa %	Dry weight of food eaten mg.	Dry weight of food eaten / Dry weight of pupa
70%	14·19	33	22·5	6·5	71·1	43·00	6·61
,,	14·66	33	24·2	8·0	66·9	45·00	5·62
,,	14·75	33	24·5	8·0	67·3	46·00	5·75
,,	14·20	33	29·2	9·0	69·2	54·00	6·00
,,	14·28	33	27·5	8·5	69·1	51·00	6·00
,,	15·43	35	24·5	8·0	67·3	50·00	6·25
,,	13·63	36	26·5	8·8	66·8	61·82	7·02
,,	14·30	36	23·5	8·0	66·0	51·82	6·48
,,	14·10	37	25·5	8·0	68·6	51·00	6·37
,,	14·62	37	27·0	8·5	68·5	50·50	5·94
,,	14·14	37	23·5	7·5	68·1	48·50	6·47
,,	13·47	38	23·5	8·0	66·0	53·82	6·73
,,	15·38	38	25·5	8·0	68·6	55·00	6·87
,,	14·86	40	31·0	10·7	65·5	69·82	6·52
,,	14·57	40	24·0	7·7	67·9	47·00	6·10
,,	14·64	42	27·8	9·0	67·6	56·32	6·26
,,	13·89	42	23·5	7·5	68·1	51·82	6·91
Average	14·42	36·6	25·5	8·2	67·8	52·14	6·35
20%	6·53	47	19·0	6·5	65·8	57·30	8·81
,,	8·27	48	18·0	6·1	66·1	53·82	8·82
,,	6·93	48	14·5	5·0	65·5	45·52	9·10
,,	6·37	48	18·5	6·2	66·5	58·32	9·40
,,	9·84	48	19·0	6·2	67·4	67·00	10·80
,,	4·60	49	19·5	5·8	70·3	55·80	9·62
,,	5·93	51	21·3	7·3	65·7	65·00	8·90
,,	6·01	51	18·3	6·0	67·2	51·00	8·50
,,	6·01	51	18·0	6·3	65·0	51·00	8·10
,,	12·18	52	18·5	6·2	66·5	51·30	8·27
,,	11·82	52	18·8	6·5	65·4	55·20	8·49
,,	6·92	54	17·9	6·2	65·4	55·00	8·87
,,	7·44	55	21·2	8·0	62·3	64·00	8·00
,,	7·31	65	20·6	7·2	65·0	55·50	7·70
,,	7·45	65	17·1	6·1	64·3	58·00	9·51
,,	7·22	72	19·5	5·9	69·7	64·20	10·88
Average	7·55	53·5	18·7	6·3	66·1	56·75	8·98
>0%	1·00	63	13·7	4·4	67·9	68·1	15·48
,,	·42	64	15·7	5·3	66·2	64·5	12·17
,,	·97	64	13·7	4·9	64·2	65·5	13·37
,,	·00	66	17·3	6·5	62·4	81·7	12·57
,,	2·05	66	18·4	6·5	64·7	85·0	13·08
,,	1·79	68	14·8	5·1	65·5	70·0	13·73
,,	1·63	71	15·1	5·3	64·9	71·0	13·40
,,	1·14	72	15·4	5·0	67·5	66·5	13·30
,,	1·64	72	14·2	4·9	65·5	73·2	14·94
,,	1·59	75	16·8	6·5	61·3	71·0	10·92
,,	·90	82	17·2	7·0	59·3	65·5	9·36
,,	·76	82	16·5	6·6	60·0	69·2	10·48
,,	1·40	91	19·8	7·3	63·1	85·6	11·73
,,	·79	97	17·1	6·3	63·2	74·9	11·89
,,	·00	102	11·5	4·4	61·7	61·4	13·95
Average	1·07	75·7	15·8	5·7	63·8	71·5	12·69

in the temperature. For most of the time it was almost constantly 18°, but rose towards the end to 21°. At this lower temperature the larval period was nearly twice that at 25°. Comparing the results at these two temperatures (Tables II, III and V) we find that the weight of the pupa is significantly higher at the lower temperature, which is in line with observations frequently made. Water contents of food and pupae are virtually the same at the two temperatures, and there is no significant difference in "net utilisation," which is therefore dependent on humidity and not on period of development.

TABLE III.

Ephestia kuehniella *grown at* 70% *Relative Humidity. Temperature* 21°C.

Relative humidity	Moisture content %	Larval period days	Wet weight of pupa mg.	Dry weight of pupa mg.	Water content of pupa %	Dry weight of food eaten mg.	Dry weight of food eaten / Dry weight of pupa
70%	13·57	58	30·7	12·2	60·3	53·64	4·40
,,	13·34	60	31·5	10·0	68·2	72·04	7·20
,,	13·95	62	29·1	9·1	69·1	53·24	5·85
,,	13·95	62	31·7	10·0	68·5	61·94	6·19
,,	13·59	62	32·0	10·0	68·7	64·04	6·04
,,	12·37	63	29·0	9·5	67·2	53·24	5·60
,,	12·32	63	31·9	11·0	65·5	61·24	5·57
,,	12·43	63	26·0	8·5	67·3	48·34	5·69
,,	14·70	64	32·1	10·9	66·0	72·14	6·62
,,	14·13	64	32·1	10·9	66·0	66·54	6·10
,,	13·38	65	32·7	11·2	65·7	65·24	5·82
,,	13·41	65	28·6	9·5	66·8	59·74	6·29
,,	13·21	65	29·2	9·0	69·2	59·64	6·63
,,	15·48	66	35·9	12·2	66·0	74·04	6·07
,,	13·39	66	25·9	8·0	69·1	51·14	6·39
,,	13·54	67	33·5	11·1	66·9	73·84	6·65
,,	14·46	68	40·0	14·1	64·8	80·24	5·69
,,	13·79	69	27·9	9·0	67·7	57·24	6·36
Average	13·61	64	31·1	10·3	66·8	62·64	6·06

Dermestes vulpinus.

The diet consisted of 49 per cent. dried brewers yeast (Glaxo Lab.), 49 per cent. fructose and 1 per cent. cholesterol. This diet had been developed in the course of an investigation into the sterol requirements of *Dermestes vulpinus* (Fraenkel, Reid & Blewett, 1941). Yeast is a satisfactory food for *Dermestes*, but for a deficiency of cholesterol, and the highly hygroscopic fructose maintains a relatively high water content in the diet. It may also, possibly, render the texture favourable for the larvae, but is not considered to be important as a food. After mixing the dry ingredients, the diets were left standing at the humidities required for 1–2 weeks before use. As with *Ephestia*, each larva was reared singly, starting with a newly-hatched larva on 500 mg. of food. As soon as the pupa was formed, pupa and residue of food were weighed wet and dry. The cast moults are found on the top of the food and are easily counted.

The results, given in Table IV and summarised in Table V, are similar to those described for *Ephestia*. The number of moults increases with decreasing humidity. This is probably due to the increase in the larval period. Gay (1938) demonstrated an increase in the number of moults with increasing larval period on different diets. The larval period greatly lengthens as the humidity decreases from 70 to 50 and

TABLE IV.

Dermestes vulpinus *grown at* 70%, 50% *and* 30% *Relative Humidity.*

Relative humidity	Moisture content of food %	Larval period days	No. of moults	Pupa			Dry weight of food eaten mg.	Dry weight of food eaten / Dry weight of pupa
				Wet weight mg.	Dry weight mg.	Water content %		
70%	20·31	35	5	43·6	19	56·4	88·35	4·65
,,	19·67	,,	6	43	19·1	55·6	90·25	4·72
,,	20·13	,,	5	43	18	58·1	85·25	4·73
,,	20·72	,,	5	36	15·6	56·7	76·85	4·93
,,	20·49	,,	6	48	19	60·4	93·45	4·91
,,	20·06	,,	6	40	16	60·0	79·35	4·96
,,	19·63	37	6	41·8	18·6	55·5	90·45	4·86
,,	19·40	,,	6	35·7	15·2	54·4	79·95	5·26
,,	19·84	41	7	35·2	14·4	59·1	82·25	5·71
,,	18·56	42	7	52·2	22·9	56·1	113·05	4·96
,,	18·95	,,	7	33	11·9	63·9	79·95	6·72
,,	18·29	43	7	57	22·2	61·0	112·05	5·04
,,	18·33	47	7	50·3	20·1	60·0	117·15	5·83
,,	18·29	,,	6	44·6	17·8	60·1	96·35	5·41
Average	19·47	39	6·1	43·1	17·8	58·4	91·77	5·19
50%	11·83	44	6	32·1	13·6	57·6	82·65	6·07
,,	12·06	,,	7	38·8	16	58·8	98·05	6·13
,,	12·23	45	7	52	22	57·2	127·45	5·79
,,	12·28	,,	7	35·8	15·1	57·8	89·05	5·89
,,	12·08	,,	7	38·8	15·4	60·3	94·15	6·11
,,	12·18	,,	7	46·8	19·1	59·2	117·25	6·13
,,	11·79	47	7	43	17·2	60·0	104·35	6·06
,,	11·83	,,	7	43·1	17·5	59·4	105·25	6·01
,,	11·84	,,	7	31	12·1	61·0	86·25	7·12
,,	12·07	48	7	34·7	14·1	59·4	87·25	6·18
,,	11·83	50	7	42·1	18	57·2	108·25	6·01
,,	12·08	58	8	35	13·1	62·6	94·25	7·19
,,	11·72	61	8	31	12·5	59·7	76·75	6·14
Average	11·99	48·1	7·1	38·8	15·8	59·2	97·77	6·22
30%	4·29	55	7	30	13·9	53·7	92·35	6·64
,,	3·17	64	8	31·7	14·1	55·5	102·35	7·26
,,	3·84	,,	8	24·5	10·4	57·5	103·65	9·96
,,	3·90	66	7	22	8·9	59·5	79·25	8·90
,,	3·40	69	9	22·6	9·7	57·1	72·95	7·52
,,	3·82	,,	8	19·5	7	64·1	75·55	10·79
,,	3·32	,,	8	42·9	19·3	55·0	150·35	7·79
,,	3·66	76	9	18·6	6·7	64·0	78·75	11·75
,,	3·58	,,	9	26	10	61·5	97·25	9·72
,,	3·74	82	9	13·4	5	62·7	67·25	13·45
,,	3·44	90	10	15·8	5	68·4	65·25	13·05
,,	2·87	92	12	18·0	7	61·1	73·35	10·48
,,	2·88	96	11	14·9	5·3	64·4	65·45	12·35
Average	3·53	74·4	8·8	23·1	9·4	60·3	86·44	9·97

30 per cent., and these differences are highly significant. Both wet and dry weight of the pupae greatly decrease at lower humidities, the differences between the dry weight at 70 and 50 per cent. R.H. not being significant, but between 50 and 30 per cent. R.H. being highly significant. The moisture content of the pupae is nearly the same at 70 and 50 per cent. R.H. and seems to increase at 30 per cent. R.H. This increase occurred in larvae which grew most slowly and is not statistically significant.

TABLE V.

Summary and Statistical Treatment of Results.

Ephestia kuehniella (*means, standard deviations and tests for significance*).

	21°C.	25°C.		
	70% rel. hum.	70% rel. hum.	20% rel. hum.	0% rel. hum.
No. of larvae	18	17	16	15
Larval period (days)... ...	64 ±2·74	36·65 ±3·10	53·5 ±7·37	75·66 ±12·51
			p <0·001	p<0·001
Moisture content of food (%)	13·61	14·36	6·69	1·07
Wet weight of pupa (mg.) ...	31·1	25·5	18·7	15·8
Dry weight of pupa (mg.) ...	10·3 ±1·52	8·21 ±0·89	6·34 ±0·69	5·73 ±0·89
		p= ·01 -- ·001	p<0·001	p<0·05
Moisture content of pupa (%)	66·8	67·8 ±1·39	66·13 ±1·92	63·83 ±2·40
			p=0·01–0·001	p=0·01–0·001
Dry weight of food eaten per pupa (mg.)	62·64	52·14	56·75	71·5
$\frac{\text{Dry weight of food}}{\text{Dry weight of pupa}}$	6·06 ±0·60	6·32 ±0·42	8·98 ±0·90	12·68 ±1·64
		p=0·1–0·2	p<0·001	p<0·001

Dermestes vulpinus (*means, standard deviations and tests for significance*).

	70% rel hum.	50% rel. hum.	30% rel. hum.
No. of larvae	14	13	13
Larval period (days)	39 ±4·56	48·15 ±5·35	74·46 ±12·34
		p<0·001	p<0·001
Number of moults	5–7	6–8	7–12
Moisture content of food (%)... ...	19·55	11·99	3·53
Wet weight of pupa (mg.)	43·1	38·8	23·1
Dry weight of pupa (mg.)	17·84 ±3·00	15·82 ±2·88	9·41 ±4·24
		p=0·1–0·2	p<0·001
Moisture content of pupa	58·4 ±2·69	59·2 ±1·57	60·3 ±4·39
		p= ·3	p= ·4
			p= ·2
Dry weight of food eaten per pupa ...	91·77	97·77	86·44
$\frac{\text{Dry weight of food}}{\text{Dry weight of pupa}}$	5·21 ±0·63	6·21 ±0·41	9·97 ±2·25
		p<0·001	p<0·001

The amount of food eaten appears to be highest at 50 per cent. and lowest at 30 per cent. R.H. This is of no significance considering the great differences in the weight of the pupae. If the amount of food eaten is calculated per unit body substance produced, it is seen that to produce 1 mg. of dry pupal substance 5·2 mg. of dry food are required at 70 per cent., 6·2 mg. at 50 per cent., and nearly 10·0 mg. at 30 per cent. R.H. The differences between 70 and 50 per cent., and between 50 and 30 per cent. are highly significant.

Discussion.

The problem of how insects acquire and conserve their water under dry conditions has been widely discussed amongst entomologists and ecologists, and the suggestion has frequently been made that certain insects derive most if not all of their water from the combustion of food. Babcock (1912), in support of this view, suggested that the passing out of a dry urine as uric acid, instead of urea in solution, was one of the means insects have developed for the purpose of conserving water. Schulz (1930) claimed that the meal worm larva, when fed on bran, produced faeces 80 per cent. of which consisted of undigested bran. The faeces contained less water than the bran, and by passing large amounts of food through the gut, the insects thus extracted sufficient quantities of water from their food. These claims were not substantiated by any evidence.

The problem was subsequently studied from the slightly different aspect of how insects regulated their water requirements during starvation. Buxton (1930, 1932) stated that the fasting mealworm decreases in dry weight more rapidly at low than at high humidities, the effect being to keep the water content of the body constant. The loss of water by increased evaporation at low humidities was thus compensated by metabolising more substance. These results have not been confirmed by Mellanby (1932 a, b ; 1934; 1936 a) who failed to observe such increases in the rate of metabolism of fasting insects at low humidities. Furthermore, the view is expressed (Mellanby, 1936 b) that such an increase in the metabolic rate, even if it did occur, at low humidities would be of no advantage to the insects because it would entail an increase in the rate of evaporation. A similar conclusion was reached by Gunn and Cosway (1942) in respiration experiments with normal and desiccated cockroaches at different humidities. According to them " there is no reason to believe that, at a given body temperature, air humidity influences basal metabolic rate," or " that the desiccated condition is relieved by extra production of water." In another investigation of this kind, carried out with pupae of *Ephestia kuehniella*, Kozhanchikov (1934) stated that " at low humidities the oxidation is increased in order to compensate the evaporation of the insect body ; it leads to an increased loss of energy." The figures given do not substantiate this claim.

Mellanby's criticisms, right or wrong, certainly do not apply to our tests where the rate of utilisation of the food at different humidities was measured. The figures which have been used in our calculations, dry weight of the pupa and amount of food eaten, are open to some criticism. The larva, while preparing to pupate, loses about 10–20 per cent. of its weight. It would have been preferable to use the weight of the larva when it is at its maximum. But it is impossible to know when this state is reached and, moreover, at that stage the gut contains much undigested food, which should not be included in the weight. Pupation is a clearly defined state, and the gut then no longer contains food. To calculate " net utilisation " from the maximum larval weight, instead of the pupal weight, would have the effect of lowering its value by about 10 to 20 per cent. without altering the relative changes at different humidities. The weight of the food eaten is calculated by weighing the food at the beginning and the end of the experiment and making allowance for the water content. At the end of an experiment the food contains a certain amount of excreta and of undigested or partly digested particles which have passed through the gut. The amount of excreta are considered to be too small to alter the final result substantially. No allowance need be made for the food which has passed through the gut undigested or partly digested, since it is included in the figure for the food residue.

The information given in this paper shows very clearly for three different insects that at a lower humidity more food is required to produce a given weight of body substance than at a higher humidity. This is what was to be expected if part of the food, at the lower humidity, was required for producing additional water. The ability of the growing insect to counteract the increased evaporation under dry conditions is shown very strikingly in another set of data in the tables. The *Tribolium* pupae have the same water content at 70 and 20 per cent. R.H. The corresponding figures for *Ephestia*, 67·8 and 66·1 per cent., are nearly the same, although the small difference is statistically significant. Even at the extremely low humidity over P_2O_5 the water content, 63·8 per cent., is not so very much lower, but the variability is rather high, and it will be seen in Table II that the first 9 pupae have a higher water content. With *Dermestes*, the water content even rises from 70 to 50 and 30 per cent. R.H. These differences are not statistically significant. From the figures in Table IV it appears that the highest moisture contents, at 30 per cent. R.H., occur towards the end of the period and generally in cases where the figure for " net utilisation " is high. No explanation can be given for this phenomenon.

Apart from raising the figure of " net utilisation," a low humidity has two other effects, shown in our figures : the duration of the larval period is increased and the weight of the pupa decreases. This increase in the larval period has been shown before by Holdaway (1932) for *Tribolium confusum*, Ahmad (1936) for *Ephestia kuehniella*, and again by Fraenkel & Blewett (1943 a) for the same insects, and four others, *Ptinus tectus*, *Silvanus surinamensis*, *Lasioderma serricorne* and *Sitodrepa panicea*. The question arises whether " net utilisation " is perhaps not so much directly a function of humidity, but of the period of development or of the size of the pupa. In other words, it is conceivable that larvae which grow slowly, or which yield small pupae, consume more food to attain a given weight. A number of reasons can, however, be quoted in support of the original view, that " net utilisation " is directly dependent on humidity. If, at low humidities, part of the food is required to provide water, the insect would be expected to grow more slowly, or not to reach the same weight as a larva growing under moist conditions. With *Tribolium*, there is actually no difference in the weights of the pupae grown at 70 and 20 per cent. R.H. With *Ephestia*, the difference in the weights at 70 and 20 per cent. is significant, but perhaps not significant at 20 per cent. and 1 per cent. With *Dermestes*, the difference between 70 and 50 per cent. R.H. is not significant, but it is significant between 50 and 30 per cent. At 30 per cent., the lowest weights occur in the larvae which take longest to pupate, but this is not so with *Ephestia* at 1 per cent. Therefore, although there is a tendency for a smaller size of pupae at lower humidities, there are exceptions to this rule, and it is not possible to relate " net utilisation " directly to body weight.

As to the relation between " net utilisation " and length of larval period, such a relation undoubtedly exists in *Dermestes* growing at 30 per cent. R.H., where the pupae which were formed last show the highest figure for " net utilisation." The same tendency appears to hold at 70 per cent. R.H., but it certainly does not hold at 50 per cent. With *E. kuehniella*, within each humidity, there is no indication of " net utilisation " being related to length of larval period. Moreover, when comparing development at two different temperatures, 20° and 25°, but at the same humidity, we find a vast difference in the length of larval period, but no difference in " net utilisation." This shows clearly that " net utilisation " is related to humidity, and not to length of larval period. All three phenomena encountered at low humidities—increase in the ratio food to body weight, lengthening of larval period, and small size of the pupa—are therefore related to one cause : humidity. The insect eats more, because part of the food is utilised as water; it consequently grows more slowly and its final size is smaller.

The suggestion has been made (Schulz 1930, Buxton 1932) that insects which live on very dry food may obtain their necessary water by extracting and accumulating such small quantities of water as are present in the food. This view does not hold for the insects under investigation, not even at 70 per cent. R.H. Table VI contains

TABLE VI.

Relations between amounts of water ingested with the food, water in the pupa and water produced by additional food eaten at low humidities.

	Tribolium		*Ephestia*			*Dermestes*		
	per pupa relative humidity		per pupa relative humidity			per pupa relative humidity		
	70%	20%	70%	20%	0%	70%	50%	30%
et weight of food consumed	6·66 mg.	8·85 mg.	60·93 mg.	61·38 mg.	72·27 mg.	114·0 mg.	111·1 mg.	89·60 mg.
:y weight of food consumed	5·76 mg.	8·19 mg.	52·14 mg.	56·75 mg.	71·5 mg.	91·77 mg.	97·77 mg.	86·44 mg.
ater ingested with food...	0·90 mg.	0·65 mg.	8·79 mg.	4·63 mg.	0·77 mg.	22·23 mg.	13·33 mg.	3·16 mg.
ɔtal water in pupa ...	1·51 mg.	1·51 mg.	17·3 mg.	12·4 mg.	10·1 mg.	25·3 mg.	23·0 mg.	9·6 mg.
fference between water in pupa and water ingested with the food	0·61 mg.	0·86 mg.	8·51 mg.	7·77 mg.	9·33 mg.	3·07 mg.	9·67 mg.	6·44 mg.
rcentage of water in pupa derived from water in food ...	59·6%	43·38%	50·8%	37·3%	7·6%	87·9%	58·0%	32·9%
y weight of food consumed	5·76 mg.	8·19 mg.	52·14 mg.	56·75 mg.	71·5 mg.	91·77 mg.	97·77 mg.	86·44 mg.
y weight of food which would have been consumed at 70% rel. hum. if pupa had been of the same weight ...		5·71 mg.		40·00 mg.	36·2 mg.		82·00 mg.	48·79 mg.
lditional food eaten at lower humidity...		2·48 mg.		16·75 mg.	35·3 mg.		15·77 mg.	37·65 mg.
ater produced by additional food ...		1·24 mg.		8·37 mg.	17·6 mg.		7·10 mg.	16·94 mg.

data about the amount of water ingested with the food during the whole of the feeding period, the water contained in the pupa and, calculated from these data, the proportion of water in the insect accounted for by the water ingested with the food. It is seen that at low humidities the ingested water is only a small fraction of the water in the pupa, in the extreme case of *Ephestia* at 1 per cent. R.H. only 7·6 per cent. Even at 70 per cent. R.H., in all cases, the amount of water in the food was less than that in the pupae. It is therefore probable that the figures for "net utilisation" would be lower still at humidities higher than 70 per cent. No tests have been made so far at higher humidities, because the diet then frequently becomes mouldy. It need hardly be pointed out that the larva requires during growth a greater total amount of water than that ultimately found in the pupa because water is lost with the faeces, by evaporation from the skin and during metamorphosis from the larva to the pupa. The larva therefore derives relatively less water from water in the food than would appear from the figures given in Table VI.

It remains to be seen whether the additional food consumed at low humidities would be sufficient to produce the additional quantity of water required by the larva. For calculating this extra supply of water obtained from the additional food, the quantity eaten at 70 per cent. R.H. has to be adjusted to give the amount which would have been eaten if the pupae had been the same weight as the pupae at the lower humidities. The amounts of water yielded for 100 g. of food are 107·1 g. for fat, 55·5 g. for starch and 41·3 g. for protein (Shohl, 1939). In our calculations a yield of 50 g. water from 100 g. flour (*Tribolium, Ephestia*) and 45 g. water from the yeast-fructose diet (*Dermestes*) have been assumed. The water which is derived from combustion of the additional food at low humidities amply compensates for the difference between the water in the pupa and in the food, except for *Dermestes* at 50 per cent. R.H. These figures do not purport to give more than a very rough indication of how efficiently an insect could compensate theoretically for a deficit of water at low humidities by oxidising more food. It must be remembered (*a*) that water is derived from oxidation of the *whole* food, not only the additional amounts consumed at low humidities, (*b*) that the larva requires during development a greater total amount of water than that ultimately found in the pupa, and (*c*) that even at 70 per cent. R.H. the larva depends on water of oxidation.

It is, therefore, beyond doubt that the insects in question which normally live on dry food, acquire a substantial, or, at extremely low humidities, the greater, part of the water ultimately found in the body from oxidation of food. In man, the position is very different. About 3,000 ml. of water and 3,000 calories are required daily by an adult man. An ordinary diet yields about 12 ml. water for 100 calories (Shohl 1939). Therefore no more than about one-ninth of man's daily requirements of water are derived from food combustion.

Summary.

(1) Three insects, *Tribolium confusum, Ephestia kuehniella* and *Dermestes vulpinus*, have been grown at several humidities and the following factors have been determined: length of larval period ; water content of food and of the freshly formed pupae ; wet and dry weight of pupae and wet and dry weight of food consumed during larval development. The " net utilisation " of the food has been calculated as the ratio of dry weight of food eaten per larva to dry weight of pupa.

(2) At lower humidities more food is eaten to produce a given unit of body weight. The length of the larval period increases and the weight of the pupae decreases.

(3) More food is eaten at low humidities, because part of the food is utilised as water. As a consequence of this, the larva grows more slowly and its final size is smaller. It is shown for *Dermestes* at 30 per cent. and *Ephestia* at 1 per cent. R.H. that less than 32·9 and 7·6 per cent. of the water in the pupae can be derived from water ingested with the food.

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Since the above paper was sent to press, Auber & Raymont, in a letter to "Nature" (1944), have confirmed that pupae of *Ephestia kuehniella,* when grown at 30 and 70 per cent. relative humidity, had approximately the same water content, but report great differences in the water contents of wandering larvae, 57·3 per cent. at the lower and 73·5 per cent. at the higher humidity. From this it would appear that a regulation of the water content takes place shortly before or during pupation. In explanation of this phenomenon, the authors suggest that "the regulatory process involves the oxidation of a greater weight of reserve substances during the prepupal stage of those individuals reared in the drier environment." This suggestion made it desirable to re-investigate the mechanism by which pupae grown at different humidities acquire the same water content.

Two batches of about 100 larvae each were grown on whole meal flour at 70 and 20 per cent. relative humidity. As the fully grown larvae left the food (called subsequently "early prepupae"), they were weighed and in a number of cases dry weights and water contents were determined immediately or after 8 hours, to allow for evacuation of the gut (Table VII, A). The remaining larvae were kept singly in tubes for about 2 or 2½ days (called "late prepupae") at the respective humidities, when wet and dry weights were again determined (B). At 20 per cent. relative humidity the larvae took on the average half a day longer to pupate and it was intended to determine water contents of prepupae as near as possible to pupation. A certain number of prepupae were allowed to pupate and their water content was determined within a few hours of pupation (C). From the results so obtained, the percentage loss in dry weight from the early prepupa until the late prepupa, or the pupa, was calculated, assuming the water content of the early prepupae to be that of series A. The variations in weight and water content are large, as was to be expected from our foregoing paper.

TABLE VII.

Wet weights, dry weights and water contents of early and late prepupa, and of pupae of Ephestia kuehniella (*mean and standard deviations*).

	70% rel. hum.			20% rel. hum.		
	No.	Age		No.	Age	
A. Early prepupae ...	10	—		22	—	
Wet weight... ...			27·6 ±1·95mg.			25·5 ±3·19mg
Dry weight... ...			9·2 ±1·00mg.			9·3 ±1·34mg.
Water content ...			66·5 ±1·8%			63·7 ±1·66%
B. Early prepupae ...	11	—		21	—	
Wet weight... ...			28·5 ±2·45mg.			23·5 ±3·23mg.
Late prepupae ...		2·1 days			2·6 days	
Wet weight... ...			24·6 ±2·27mg.			19·9 ±2.60mg.
Dry weight... ...			8·0 ±0·96mg.			6·6 ±1·01mg.
Water content ...			67·0 ±1·57mg.			66·8 ±2·15mg.
C. Early prepupae ...	13			14		
Wet weight... ...			29·5 ±1·73mg.			24·2 ±1·23mg.
Pupae		2·5 days			2·9 days	
Wet weight... ...			25·2 ±1.05mg.			20·5 ±1·19mg.
Dry weight... ...			8·2 ±0·57mg.			6·9 ±0·60mg.
Water content ...			67·7 ±1·18mg.			66·5 ±1·27mg.
Percentage loss in dry weight—						
Early to late prepupa			15·8%			22·3%
Early prepupa to pupa			17·2%			21·6%

The results of these tests (Table VII) allow us to draw the following conclusions :—

1. At 70 per cent. relative humidity, the water contents from the early prepupa up to pupation remain essentially the same (instead of a fall reported by A. & R.).

2. At 20 per cent. relative humidity, the water content of the early prepupae is somewhat lower than at 70 per cent., but still much higher than that reported by A. & R. for 30 per cent. relative humidity.

3. The late prepupa and the pupa at 20 per cent. relative humidity have about the same water content as all stages at 70 per cent. relative humidity. The water content rises from the early to the late prepupa from 63·7 to 66·8 per cent. (instead of from 57·3 to 65·4 per cent. according to A. & R.). The difference between these two figures is, however, statistically significant.

4. The percentage loss in dry weight, from the early to the late prepupa, or the pupa, is about one-fifth higher at 20 per cent. than at 70 per cent. relative humidity.

The slight rise in water content between the early and late prepupa may be therefore attributed to increase in the oxidation of dry substance, an increase which, however, clearly is not due to increased rate of respiration, but to the lengthening of the prepupal period by about 20 per cent. In addition, another factor ought to be taken into consideration. Before pupation, the larva spins a cocoon and it may reasonably be assumed that inside the humidity will be considerably higher than outside, specially at low humidities. How far this will account for the rise in water content during the prepupal period cannot be stated with certainty. In some cases where the cocoon consisted of only a few threads, apparently allowing free circulation of air, the water contents of prepupae and pupae were not lower than of those living in dense cocoons.

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TWO INJURIOUS SPECIES OF PHYTOPHAGA (HALTICINAE) FROM THE IVORY COAST.

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All the described species of *Poëphila* have come from West Africa. Jacoby, in describing *Crepidodera zambiensis* in 1899, considers that it should be placed in a separate genus, and I now place it in *Poëphila*. It is very close to his two species, *P. costatipennis* and *fulvipes*. These three species have the elytra blue. Including the new species now described, the genus contains five species.

There are now 36 described species of African *Jamesonia*.

The types of these two new species have been presented to the British Museum.

Halticinae.

Poëphila flaveola, sp. n. (fig. 1).

Elongate, flavous, the elytra slightly darker, with a violaceous tinge, strongly punctate-striate, the interstices longitudinally costate. Length : 3–4 mm.

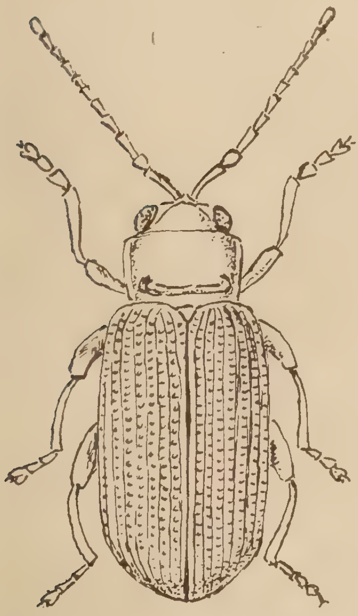

Fig. 1. *Poëphila flaveola*, Bryant, sp. n.

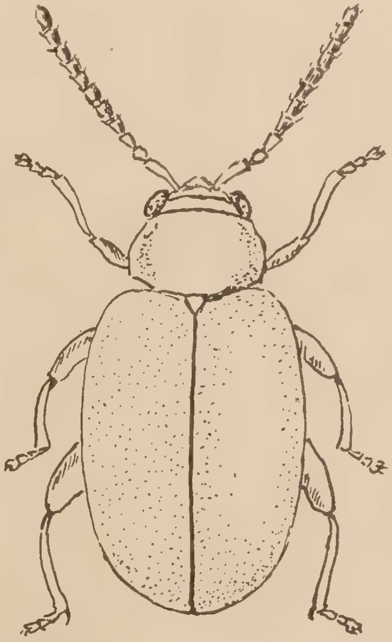

Fig. 2. *Jamesonia theobromae*, Bryant, sp. n.

♂♀.—Head flavous, impunctate, the labrum tinged with fuscous. Eyes large, shortly carinate between the antennae, and a transverse impression between the eyes. Antennae flavous, filiform, extending almost to the middle of the elytra, the first segment the longest, the second short and dilated. Prothorax flavous, transversely subquadrate, convex, the sides straight and margined, the posterior margin slightly produced at the middle, a deep transverse sinuate sulcus near the basal margin, not extending to the sides, the disc very finely and remotely punctured. Scutellum flavous, triangular, impunctate. Elytra elongate, of a slightly darker colour, tinged with violaceous, strongly punctate-striate, the punctures not rounded, the interstices longitudinally costate. Legs and underside flavous, the ventral segments of the abdomen about equal, clothed with scattered golden pubescence. ♂ slightly smaller, with the first segment of the anterior tarsi more dilated.

Ivory Coast: Bingerville, 6.ii.1943 (*H. Alibert*), 13 specimens; Ex "Gorli," (No. 47), *Onchoba echinata*, Oliver. (This tree bears a large number of seeds which are known as "Gorli" seeds.)

Gold Coast: British Museum Coll. No. 67–56, 1 specimen.

Allied to *P. lacessita*, Weise, from Addah, but differs in its much larger size and paler colour.

Jamesonia theobromae, sp. n. (fig. 2).

Fulvous, the eight apical segments of the antennae black, head feebly punctured on the vertex, prothorax with a few very fine punctures, the elytra more strongly punctured. Length: 4–4·5 mm.

♂♀.—Head fulvous, the labrum tinged with fuscous, a few fine punctures on the vertex. Eyes large, carinate between the insertion of the antennae, and a well marked transverse impression between the eyes. Antennae rather thickened, extending slightly beyond the base of the elytra, the three basal segments fulvous, the remainder black and more pubescent, the first segment the longest, the second and third together about equal to the first, the apical segment acuminate. Prothorax transverse, the sides rounded and contracted in front, the posterior angles strongly oblique, fulvous, nitid, very finely and not closely punctured. Scutellum fulvous, triangular, impunctate. Elytra much broader than the base of the prothorax, widest near the middle, the sides rounded to the apex, finely and closely punctured, the punctures stronger than those on the prothorax. Legs fulvous, the posterior tibiae with a sharp spine at the apex. Underside fulvous, the first ventral segment of the abdomen the longest, the second to the fourth about equal to each other, and clothed with golden pubescence.

Ivory Coast: Bingerville, 1.iii.1943 (*H. Alibert*), 6 specimens on cacao leaves (No. 66).

Allied to *J. castanea*, Jac., but smaller, and the antennae different, *J. castanea*, Jac., having the three apical segments pale.

MERCURY AS A CONTROL FOR STORED GRAIN PESTS.

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1. Introduction.

Among the methods of grain pest control practised by the native cultivators of India at least one appears, in the light of recent knowledge, to have a sound scientific basis. A custom practised by the raiyats of Mysore for the protection of stored pulses against the bean beetle consists of placing in the storage container an excavated soap nut containing a drop of mercury. Attention was first called to this custom by Kannan (1920). In a series of experiments he found that reproduction of this pest was prevented by placing a small quantity of this metal in the storage container. He showed that the action was upon the eggs, which if subjected for a short period to the vapour of mercury failed to hatch. These results were confirmed by Larson (1922). The investigations of Dutt and Puri (1929) showed that the rice weevil (*Calandra oryzae*) could be similarly controlled and that tin amalgam when substituted for mercury proved equally effective. The germination of wheat stored for long periods with mercury was not found to be adversely affected, neither was any untoward effect noticed in the health of humans consuming such grain. More recently mercury vapour has been shown to be very toxic to the eggs of the flour beetle (*Tribolium confusum*). Other stages of this insect, however, appear to be unharmed by it (Gough, 1938).

The writer has recently used mercury and compounds of mercury with success for the control of other insect pests, and in the following experiments an attempt has been made to assess the efficacy of mercury for the control of several of the more common grain insects.

2. Technique.

In the preliminary experiments, wide-necked, straight-sided bottles known to the trade as the "kali" type were used. These were of two sizes, the smaller holding approximately 250 cc. when filled to the shoulder and the larger double this quantity. Cork stoppers were used, and to avoid asphyxiation of the contents, each was bored with a hole 3/10ths of an inch in diameter. To prevent escape of the grain insects, a single thickness of book muslin was placed under the cork and also tied round the stoppered end of the bottle.

Throughout these experiments, the insecticides were placed in small containers before use, direct contact with the grain or the insect being therefore avoided. The container consisted of a single layer of filter paper surrounded by another of book muslin. Filter paper was used on account of its porosity. Into each bottle a single container holding the insecticide was placed. This was pushed about 1½ inches below the surface of the grain.

With one exception the cereal used throughout was wheat, and all samples were purchased as free from grain insects. In each experiment all containers were of similar size and construction and were furnished with an equal quantity of grain taken from the same bulk sample. After insertion of the insecticide, all containers were immediately infected with the same number of live adult individuals of the pest concerned. Incubation of all containers in an experiment was carried out under identical conditions.

The criterion used for the termination of any experiment was the condition of the grain in the untreated (control) containers. This was necessary as certain experiments were carried out under room conditions whilst in others the temperature of the storage chamber was controlled. Rapid insect development is accompanied by the liberation of water. This is absorbed by the grain which softens, cakes together and becomes a suitable medium for the development of moulds. An experiment was stopped when approximately half the contents of the untreated bottles had become caked together in this fashion. The adult insects were then separated from the grain by sieving or hand picking and then counted. The contents of each container were recorded separately.

3. Experiments on the Control of the Grain Weevil.

The first eight experiments were carried out on the grain weevil, *Calandra granaria*, L.

Experiment 1.

Small kali bottles were used, and in each were placed 100 cc. of clean wheat and 100 adult grain weevils. The various treatments carried out are shown in Table I, together with the number of weevils produced in the various containers and the condition of the grain in these at the end of the experiment. There were duplicate bottles of each treatment, and the number of weevils given is the average of the two counts. The experiment was set up on 3.11.38 and terminated on 8.3.39. It was carried out at room temperature.

TABLE I.

The Control of the Grain Weevil.

Treatments	Number of weevils inserted 3.11.38	Total number of weevils recovered 8.3.39	Condition of the grain 8.3.39
(1) Mercury (metallic) 5 grm.	100	100	Hard, practically undamaged
(2) Calomel (mercurous chloride) 5·8 grm.	100	187	Hard, a few grains damaged
(3) Control (untreated) ...	100	1,264	Very soft, much caked and moulded

Experiment 2.

This was a repetition of the previous experiment with the exception that tin amalgam was included as an additional treatment. This was made by grinding the two elements together in the proportion of 3 parts of mercury to 2·4 parts of tin. The experiment was set up on 14.11.38 and ended 8.3.39. It was carried out at room temperature. Details of the treatments and the results obtained are shown in Table II.

TABLE II.

The Control of the Grain Weevil.

Treatments	Number of weevils inserted 14.11.38	Total number of weevils recovered 8.3.39	Condition of the grain 8.3.39
(1) Mercury (metallic) 5 grm.	100	100	Hard, practically undamaged
(2) Calomel 5·8 grm.... ...	100	102	,,
(3) Tin amalgam 8·3 grm. ...	100	99	,,
(4) Control	100	925	Very soft, much caked and moulded

The results show that small quantities of either mercury or tin amalgam are capable of preventing the reproduction of the grain weevil. Calomel appears to have a considerable restraining effect upon this process without completely preventing it. The condition of the grain in the treated and untreated containers was itself an indication of the effectiveness of the treatment. The grain in the untreated containers was very soft, heavily moulded and of little commercial value. The mercury treated samples were, in contrast, hard and clean, only about one per cent. of the grains having been damaged by the adult weevils.

Experiment 3.

This experiment was carried out in large kali bottles each holding 500 cc. of wheat (approximately 14 oz.). The stock from which this grain was taken was found to be slightly infested with weevils. Before using the grain in this experiment, it was carefully sieved to remove all adults. Treatments 12 and 13 were not infected with weevils; in the remainder 100 adults were placed in each container. The zinc amalgam was prepared by heating together equal weights of zinc and mercury and was powdered before being used. The experiment was set up on 8.2.39, and a first examination was made some four months later (19.6.39) when all adult weevils were removed. A second count was taken on 24.8.39, and following this, an estimate was made of the moisture content of the grain and of the damage sustained in the various treatment containers. The results obtained are given in Table III. Each treatment was duplicated, and the figures given are the average. The experiment was carried out at room temperature.

It will be seen from the table that weevils were recovered from treatments 12 and 13, although none was inserted when the experiment was set up. These were apparently derived from the original infection, being present at the time of sieving as immature individuals inside the grain. From this nucleus, flourishing colonies evolved in treatment 13, but in treatment 12 those weevils which emerged failed to reproduce.

TABLE III.

The Control of the Grain Weevil.

Treatments	No. of weevils inserted 8.2.39	First examination 19.6.39			Second examination 24.8.39		
		Weevils alive	Weevils dead	Total weevils	Total weevils	Moisture content of grain %	No. of grains damaged by weevils %
1. 4 grm. Zinc amalgam	100	68	61	129	2	10·0	1·5
2. 2 grm. Zinc amalgam	100	99	56	155	1	10·5	2·5
3. 1 grm. Zinc amalgam	100	119	55	174	1	10·4	2·0
4. 0·5 grm. Zinc amalgam	100	117	61	178	485	11·3	10·0
5. 0·25 grm. Zinc amalgam	100	205	59	264	824	14·0	30·5
6. 2 grm. Zinc	100	649	56	705	781	15·0	35·5
7. 2 grm. Mercury... ...	100	54	57	111	1	10·1	1·0
8. 0·5 grm. Mercury ...	100	61	45	106	0	10·2	1·0
9. 2 grm. Calomel... ...	100	76	57	133	0	10·5	1·5
10. Control (untreated) ...	100	1077	52	1129	1076	17·5	39·0
11. Control (untreated) ...	100	983	54	1037	1119	18·0	37·0
12. 4 grm. Zinc amalgam ...	0	9	1	10	0	9·9	0
13. Untreated	0	86	0	86	221	11·0	8·5

Mercury is again seen to be very effective, the difference between the number of weevils recovered at the first examination and the number inserted at the beginning of the experiment is probably attributable to the residuum of the primary infection. The effectiveness of the zinc amalgam appears to increase as the concentration of the amalgam is increased. At the higher rates protection was almost complete after a few months of storage.

The weevil mortality recorded at the first examination shows little difference in the various treatments and suggests that mercury vapour has little effect on the viability of the adults of this insect.

The condition of the grain, as shown by its moisture content or number of grains hollowed out, is an additional measure of the effectiveness of the various treatments. High moisture content and severe weevil damage are both seen to be directly correlated with heavy weevil infestation. Bottles from treatments 7 and 10 are set aside and re-examined on 14.2.40. The contents of the untreated samples were then very soft, blackish in colour and possessed a strong sour smell; the mercury treated grain, however, was hard and practically undamaged. The moisture content of the two samples was now found to be 56·5 per cent. and 10·1 per cent. respectively.

Certain observations were also made on the effect of storage in mercury vapour on the viability of the grain. Tests were carried out on samples taken from treatment 12 in which the zinc amalgam was retained throughout. Samples removed on 13.3.39, 7.9.39 and 11.1.40 gave germination percentages of 96, 97 and 96 respectively. The germination determined at the beginning of the experiment was 96 per cent. These results indicate that the viability of the sample was not adversely affected by some eleven months' storage in mercury vapour.

Experiment 4.

This experiment was carried out in small kali bottles each containing 200 c.c. of grain. Treatments 15 and 16 were not infected; in the remainder 100 adult weevils were placed in each container. The insecticides used in treatments 1, 11 and 12 had been utilised in two previous weevil experiments, the combined length of which was seven months. All others were freshly prepared or taken from stock and were being used for the first time. Zinc amalgam was prepared as in the previous experiments. Empty paper-muslin containers were placed in treatment 14 (control) to determine the effect of such material on weevil reproduction. The experiment was set up on 23.6.39 and was carried out at room temperature. There were duplicates of each treatment, and the results are set out in Table IV.

TABLE IV.

The Control of the Grain Weevil.

Treatments	No. of weevils inserted 23.6.39	First examination 3.10.39			Second examination 19.10.39		
		Weevils alive	Weevils dead	Total weevils	Total weevils	Moisture content of grain %	No. of grains damaged by weevils %
1. 5 grm. Mercury... ...	100	84	16	100	0·5	12·0	3
2. 2 grm. Mercury... ...	100	83	16	99	1	—	2·5
3. 0·5 grm. Mercury ...	100	87	13	100	0·5	—	2
4. 0·25 grm. Mercury ...	100	78	21	99	1	11·9	1·5
5. 10 grm. Zinc amalgam...	100	87	13	100	0	—	1·5
6. 4 grm. Zinc amalgam ...	100	83	17	100	0·5	12·1	2
7. 2 grm. Zinc amalgam ...	100	88	12	100	0·5	—	2·5
8. 1 grm. Zinc amalgam ...	100	84	16	100	0·5	—	1·5
9. 0·5 grm. Zinc amalgam	100	78	22	100	1	—	2·5
10. 0·25 grm. Zinc amalgam	100	104	21	125	15	12·8	5
11. 8·3 grm. Tin amalgam...	100	220	22	242	152	14·1	13
12. 5·8 grm. Calomel ...	100	122	21	143	17	12·6	6·5
13. Control	100	1058	19	1077	296	18·8	46·5
14. Control + Container ...	100	1046	24	1070	372	—	46
15. Untreated	0	0	0	0	0	11·4	0
16. 5 grm. Mercury... ...	0	0	0	0	0	—	0
17. 5 grm. Zinc	100	869	23	892	335	—	45·5
18. 5 grm. Corrosive Sublimate...	100	928	26	954	217	18·3	44·5

Over the range of concentrations used, mercury is seen to have prevented all reproduction. Zinc amalgam appears to have been equally effective except at the lowest rate (treatment 10) where a slight increase occurred. The inclusion of empty paper-muslin containers (treatment 14) was ineffective, whilst reproduction in the presence of zinc or corrosive sublimate (treatments 17 and 18) progressed as in the untreated containers. Substantial increase occurred in the presence of tin amalgam which, when first used (experiment 2), appeared fully effective. The efficacy of the mercury and calomel in treatments 1 and 12 appeared to be unaffected by previous use. High weevil populations are accompanied, as in the previous experiment, by extensive damage to the grain.

TABLE V.

Comparative Efficacy of Mercury, Calomel and Zinc and Tin Amalgams for the Control of the Grain Weevil.

Treatments	No. of weevils inserted 20.9.39	Total weevils recovered 12.12.39	Grains damaged and*		Total grains damaged by weevils 14.12.39 %	Moisture content of grain 14.12.39 %
			(*a*) not containing larvae or pupae %	(*b*) containing larvae or pupae %		
1. 2 grm. Mercury	100	98	2	0	2	13·4
2. 1 grm. Mercury	100	99	3	0	3	
3. 0·5 grm. Mercury	100	108	2·5	0	2·5	
4. 0·25 grm. Mercury... ...	100	108	2	0	2	
5. 0·125 grm. Mercury ...	100	116	2·5	0	2·5	13·2
6. 4 grm. Zinc amalgam ...	100	101	3	0	3	13·5
7. 2 grm. Zinc amalgam ...	100	131	4·5	0·5	5	
8. 1 grm. Zinc amalgam ...	100	781	14·3	4	18	
9. 0·5 grm. Zinc amalgam ...	100	1010	26·5	4·5	31	
10. 0·25 grm. Zinc amalgam ...	100	1292	31	3	34	18·6
11. 4 grm. Tin amalgam ...	100	785	14	6	20	16·1
12. 2 grm. Tin amalgam ...	100	1247	19·5	5·5	25	
13. 0·25 grm. Tin amalgam ...	100	—	28·5	6·5	35	19·7
14. 2 grm. Calomel	100	721	15	5	20	15·5
15. 1 grm. Calomel	100	1042	18	3	21	
16. 0·5 grm. Calomel	100	1244	23·5	2·5	26	
17. 0·25 grm. Calomel... ...	100	1160	24·5	6	30·5	
18. 0·125 grm. Calomel ...	100	1202	32	3·5	35·5	19·1
19. Control+containers ...	100	1422	30	8	38	19·7
20. Control	100	1571	37	7	44	19·3

* From each treatment 400 grains were examined (200 from each container). Such a sample appears to be too small to give more than an approximate representation of the extent of the damage incurred.

Experiment 5.

In this experiment, the relative efficacy of mercury, calomel and zinc and tin amalgams for the control of grain weevil was tested. For each insecticide a similar range of concentrations was employed. In making the amalgams, equal weights of each constituent were used. The experiment was set up on 20.9.39 and carried out in large kali bottles each holding 500 cc. of wheat. The results given in Table V were obtained after some three months' storage at 25°C. Replicates of the mercury and zinc amalgam treatments were kept at room temperature. These were examined on 23.1.40, and the results so obtained are given in Table VI.

The data given in Tables V and VI show that metallic mercury was again the most effective treatment tested. At room temperature reproduction occurred only at the lowest mercury concentration, but, at 25°C., slight increase occurred at the three lower concentrations. This may represent a differential temperature effect tending to work in favour of the insect at the higher temperatures. Except at the highest rate, both of the amalgams and the calomel appear to have had little restraining effect upon weevil increase. Their efficiency appears to fall off rapidly with decrease in concentration. In experiments 3, 4 and 5 similar weights of zinc amalgam were tested but only when small containers were used (experiment 4) was a satisfactory control achieved.

Observations made on the contents of the grain at the end of the experiment showed that in those treatments where no weevil increase had occurred larvae and pupae were absent. Where considerable increase had occurred, immature stages of the weevil were found to be prevalent, indicating that breeding was still in progress. Certain

TABLE VI.

The Control of the Grain Weevil by Mercury and Zinc Amalgam.

Treatments	No. of weevils inserted 20.9.39	Total weevils recovered 23.1.40	Grains damaged and		Total grains damaged by weevils %
			(*a*) not containing larvae or pupae %	(*b*) containing larvae or pupae %	
1. 2 grm. Mercury	100	100	0·5	0	0·5
2. 1 grm. Mercury	100	99	0·5	0	0·5
3. 0·5 grm. Mercury	100	99	0	0	0
4. 0·25 grm. Mercury	100	100	1	0	1
5. 0·125 grm. Mercury	100	111	2	0	2
6. 4 grm. Zinc amalgam	100	103	1	0	1
7. 2 grm. Zinc amalgam	100	161	7·5	3·5	11
8. 1 grm. Zinc amalgam	100	1362	24·5	6·5	31
9. 0·5 grm. Zinc amalgam ...	100	1415	34	4·5	38·5
10. 0·25 grm. Zinc amalgam ...	100	1025	29·5	3·5	33
11. Control+containers	100	1020	26	3	29
12. Control	100	1619	35	6	41

cases were noted, however, in which the number of weevils recovered was greater than the infection number, but the examination of the grain failed to reveal either larvae or pupae (Table V, treatments 3, 4, 5, 6, and Table VI, treatments 5 and 6). This suggests that the limited breeding achieved occurred towards the beginning of the experiment.

Experiment 6.

This experiment was carried out in cylindrical galvanised iron bins each having a capacity of approximately 1¾ bushels (14·2 gal.). Into each of five bins, 60 lb. of wheat was placed. Metallic mercury only was used in this experiment as previous results had shown it to be the most satisfactory of the mercurials tested. In bins 1 and 2 mercury was used at the rate of 0·5 grm. per 14 oz. of grain, a concentration that under bottle conditions was known to give satisfactory control. At this rate, the proportionate weight of mercury per 60 lb. of grain is 34·3 grm. For bin 1 this dosage was subdivided into fifteen approximately equal portions, each of which was placed in paper-muslin containers. For bin 2 the same weight was sub-divided five times. The mercury rate in bin 3 was decreased to 0·33 grm. per 14 oz. of grain but the number of containers into which the total requirement was sub-divided was increased to 20. A higher rate than necessary to give control under bottle conditions was used in bin 4. The mercury required, however, was divided between five containers.

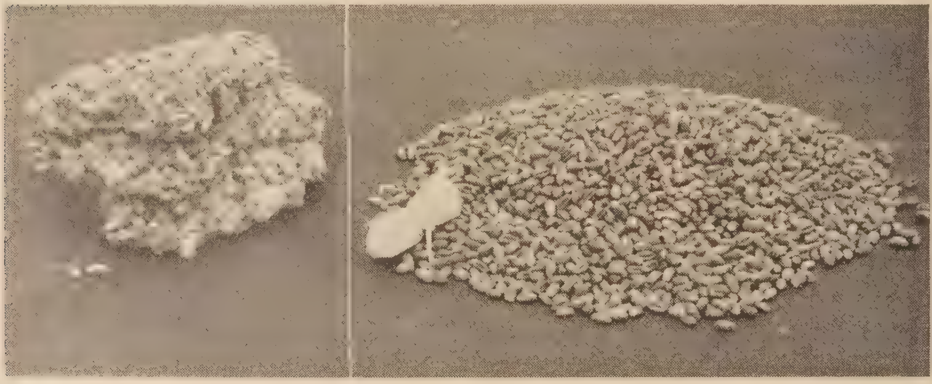

Fig. 1. *Experiment* 6. Comparison of grain from treated and untreated bins. *Left*: Grain from control bin (5) soft, heavily moulded and caked. *Right*: Grain from bin 1, hard, clean and almost undamaged, also mercury container.

The appropriate mercury containers for each bin were distributed as regularly as possible among the grain.

The fifth bin remained untreated and served as a control.

Into each of the five bins 1,100 adult grain weevils were placed. Their escape was prevented by a double layer of book muslin tied over the open end of the bin beneath the cover. The experiment was set up on 31.8.39, and the bins were placed in a constant temperature chamber at 25°C. An examination of the bin contents was made some three months later (27.11.39), and the results obtained together with the treatments used are shown in Table VII.

The results show that a 35-fold increase in the number of weevils occurred in the untreated bin since the beginning of the experiment. In bins 2, 3 and 4 small increases only occurred, whilst in bin 1 fewer weevils were recovered than originally placed in the container. A comparison of the results obtained in bins 1 and 2 shows that the

TABLE VII.

The Control of Grain Weevil in Bins : Treatments and first Examination Data.

Bin No.	Weight of mercury used per 60 lb. of grain. grm.	Equivalent rate of mercury per 14 oz. of grain. grm.	No. of containers into which dosage sub-divided	*Relative total surface area of mercury %	No. of weevils inserted 31.8.39	No. of weevils recovered 27.11.39	Temperature of grain 6 in. below surface. °C.
1	34·3	0·5	15	100	1,100	1,052	15·7
2	34·3	0·5	5	67·9	1,100	1,374	15·9
3	22·9	0·33	20	82·0	1,100	1,150	15·5
4	51·4	0·75	5	88·9	1,100	1,161	15·6
5	Control (untreated)	—	—	—	1,100	35,270	22·1

In calculating the relative surface areas, the mercury in each paper-muslin container was assumed to be in the form of a sphere. The bins were removed from the storage chamber and allowed to stand four days under room conditions before the temperature of the grain was recorded.

same weight of mercury was more effective when divided between fifteen paper-muslin containers than when divided between five. Increased rate of sub-division is accompanied by increase in total surface area ; in bin 1 the surface area of the mercury was greater by some 32 per cent. than that in bin 2. Increased efficiency resulting from sub-division is also apparent from the results obtained for bins 3 and 4. In both, a similar degree of weevil control was obtained although the weight of mercury used in bin 4 was more than double that used in bin 3. A high rate of sub-division in bin 3, however, compensated for this and brought the total surface area of the mercury in this bin to within 7 per cent. of that in the other.

The condition of the grain in the treated bins was very similar in each case. Damaged grains could be found only with difficulty, and the samples were clean and hard. In the untreated container the grain was soft, much moulded and showed abundant signs of weevil damage. On the bottom of the bin a layer about 2 ins. thick had become caked together and could be removed as lumps. The temperature of the grain in this container was some 6° higher than that in the mercury-treated containers.

After counting, all the weevils were replaced in the appropriate bins with the exception of 100 from each treatment, which were retained for use in the next experiment. The bins were then returned to a constant temperature of 25°C. until 14.12.39, when they were removed to room conditions and examined some five days later. The results obtained are given in Table VIII.

With the exception of bin 1, further slight increases in number of weevils occurred in all the mercury treatments during the second period of storage.

An estimate of the extent of damage incurred in the various treatments was obtained by an examination of 400 grains from each bin. In the untreated bin more than a quarter of the grain had been damaged, whereas in the treated containers the injury was, in each case, less than 1 per cent. In the untreated grain also, immature stages of the weevil were commonly found ; these were absent from the treated samples. This indicated that breeding in the treated bins had now ceased. As in previous experiments, rapid weevil reproduction is seen to be accompanied by a considerable increase in the moisture content of the grain.

TABLE VIII.

The Control of Grain Weevil in Bins, second Examination: Weevils recovered and Condition of the Grain 19.12.39.

Bin No.	No. of weevils replaced 28.11.39	No. of weevils recovered 19.12.39	Grains damaged and (a) not containing larvae or pupae %	Grains damaged and (b) containing larvae or pupae %	Moisture content of grain 19.12.39	Temperature of grain 6 in. below surface 19.12.39 °C.
1	952	925	0·75	0	13·4	17·2
2	1,274	1,420	0·25	0	13·6	17·2
3	1,050	1,109	0·25	0	13·7	17·1
4	1,061	1,136	0·5	0	13·6	17·1
5	35,070	36,500	21·5	6	18·0	20·8

The weevils recovered from the mercury treated bins were restored, after counting, to their appropriate bins. Those from the untreated container, however, were not returned. The bins were then stored at room temperature until 7.2.40 when their contents were again examined. The results obtained are given in Table IX.

TABLE IX.

The Control of Grain Weevil in Bins, third Examination: Weevils recovered and Condition of the Grain 7.2.40.

Bin No.	No. of weevils replaced 19.12.39	No. of weevils recovered 7.2.40	No. of grains damaged by weevils %	Moisture content of grain %	Temperature of grain 6 in. below surface °C.	Germination percentage tested 8.2.40
1	925	882	0·25	12·6	19·1	76
2	1,420	1,378	0·5	12·7	19·0	89
3	1,109	1,086	1·0	12·5	19·1	81
4	1,136	965	0·25	12·5	19·0	78
5	Nil	11,160	37·25	18·2	24·6	2

All the mercury treatments now appeared to be fully effective as no weevil increase occurred in either container and no immature stages were found in the grain. In the control bin a further 11,000 weevils were recovered and immature individuals were frequent. In all the treated bins the grain was hard, clean and practically undamaged. In the untreated container, however, it was soft, heavily infected with mould and severely damaged by weevil. A layer on the bottom of the container, some 2 ins. in thickness, had again become caked (see fig. 1). This was found to have a moisture content of 49·2 per cent. The remainder of the grain in this bin was also found to have a much higher water content than that in either of the treated containers. Much of this moisture appears to originate from the weevils as an end product of respiration. It is rapidly absorbed by the grain, which, with increased moisture content, itself commences oxidative activity. Respiration in insects and grain is also accompanied by the liberation of heat. This, in turn, leads to increased weevil activity, so that the two processes, the production of moisture and of heat, gather speed with time. Both are accumulative and interdependent, the weevil being the initiator of the cycle. Heavy weevil infestations are therefore normally accompanied by heating and high moisture content of the grain. From Table IX it will be seen that heavy weevil attack also ruined the germination of the grain.

Experiment 7.

This experiment was carried out to determine the effect of storage with mercury upon the subsequent reproductive capacity of the grain weevil. From each of the mercury treated bins of the previous experiment, one hundred live adult weevils were removed on 27.11.39, some three months after the commencement of this experiment. From the untreated container also two hundred adults were removed at the same time. The weevils from each bin were placed in large kali bottles each containing 500 cc. of wheat, the latter being taken from the same bulk sample as that used in the previous experiment. No insecticidal treatments were included, and the bottles were stored at 25°C. They were re-examined on 8.2.40 when the data given in Table X were obtained.

TABLE X.

The Effect of Storage with Mercury on the subsequent reproductive Capacity of the Grain Weevil.

Bottle No.	No. of weevils inserted 27.11.39	Source of weevils in Experiment 6	No. of weevils recovered 8.2.40		
			(*a*) Alive	(*b*) Dead	(*c*) Total
1	100	bin 1 (treated)	1065	65	1130
2	100	bin 2 (treated)	1329	47	1376
3	100	bin 3 (treated)	1065	46	1111
4	100	bin 4 (treated)	1155	39	1194
5	100	bin 5 (untreated)	923	38	961
6	100	bin 5 (untreated)	1415	34	1449

The results indicate that weevils which have been subjected to prolonged storage with mercury can, if placed in a suitable environment, resume breeding at a normal rate.

Experiment 8.

The results given by experiment 6 (bin experiment) showed that the efficiency of a given weight of mercury in the control of the grain weevil was increased by subdivision. This process increases the total surface area from which evaporation takes place and thereby decreases the time required to build up a given toxic concentration of mercury vapour. The technique of handling very small weights of mercury in separate paper-muslin containers was found to be slow and difficult. This was overcome by the incorporation of very finely divided mercury in a solid porous base. A mixture was made up containing 27 per cent. of metallic mercury, most of which was found to be in the form of globules of microscopic dimensions. This fine state of sub-division and the very porous nature of the base indicated that the mixture would be well suited for the rapid production and release of mercury vapour. The following experiment was carried out using this material.

The Control of the Grain Weevil by Mercury " Brick " Mixture containing 27 *per cent. of Metallic Mercury.*

Large kali bottles, each holding 500 cc. of wheat (approx. 14 oz.), were used. The mercury mixture was placed in paper-muslin containers as in previous experiments. There were two groups of treatments ; in the A group the weight of mixture used was varied so that its mercury content ranged from 1 grm. to 1/16th grm. per container. In groups B the weight of the mixture itself ranged from 2 grm. to $\frac{1}{16}$ grm. per container. Into each bottle 100 grain weevils were placed and prevented from escaping as in previous experiments. The experiment was set up on 15.1.40, and a first count of weevils was made on 1.4.40, at which time the grain in the untreated containers was very heavily infested and becoming caked. After the examination, the adult weevils were returned to their appropriate bottles in group A ; in group B they were discarded. Some ten months later (11.2.41) the weevils were again counted and the condition of the grain in the various containers noted. Details of the treatments carried out and the results obtained are shown in Table XI. Each treatment was duplicated and the figures given are the average.

TABLE XI.

The Control of the Grain Weevil by Mercury " Brick " containing 27 *per cent. Metallic Mercury.*

No.	Treatments		No. of weevils inserted 15.1.40	No. of weevils recovered 1.4.40		No. of weevils recovered 11.2.41	Condition of the grain 11.2.41
	Weight of " brick " used	Weight of mercury incorporated therein					
A. 1	3·703 grm.	1·00 grm.	100	97	weevils replaced	95	Hard, almost undamaged
A. 2	1·851 ,,	0·50 ,,	100	99		97	,,
A. 3	0·926 ,,	0·25 ,,	100	100		98	,,
A. 4	0·463 ,,	0·125 ,,	100	102		102	,,
A. 5	0·261 ,,	0·062 ,,	100	100		98	,,
B. 1	2·00 ,,	0·54 ,,	100	99	weevils removed	0·5	,,
B. 2	1·00 ,,	0·27 ,,	100	100		0	,,
B. 3	0·50 ,,	0·135 ,,	100	100		1	,,
B. 4	0·25 ,,	0·067 ,,	100	98		0	,,
B. 5	0·125 ,,	0·034 ,,	100	99		1	,,
B. 6	0·100 ,,	0·027 ,,	100	100		0·5	,,
B. 7	0·062 ,,	0·017 ,,	100	716		Abundant	Very soft, caked and mouldy
Control (untreated)		... ...	100	1,500		Abundant	Very soft, caked and mouldy

In the A group of treatments, the mercury mixture is seen to be effective over the whole range of concentrations used. In the B group, however, the lowest effective treatment rate is reached at B.6 ; considerable weevil increase occurring in B.7. With this exception, no weevil increase occurred in either of the treated containers, the grain at the end of the experiment being clean, hard and almost undamaged. In the untreated containers and those of B.7, the grain was very soft, with a strong odour, suggesting sourness and of little or no value.

These results show that mercury in the finely divided form is a highly effective method of controlling the grain weevil. In the bin experiment (experiment 6), in which a few, relatively large, globules of mercury were used in each container, the lowest effective rate was found to be ·33 grm. of mercury per 14 oz. of grain. At this rate 100 tons of grain would require 186·5 lb. of mercury. Using the mercury mixture, however, as little as 0·027 grms. of mercury sufficed for 14 oz. of grain; the proportionate rate per 100 tons of grain being 15·2 lb. of mercury.

4. Experiments on the Control of other Grain Pests.

The insecticidal properties of mercury were also tested for the control of three other common grain pests, the Saw-toothed Grain Beetle (*Oryzaephilus* (*Silvanus*) *surinamensis*, L.), the Lesser Grain Borer (*Rhizopertha dominica*, F.) and the Angoumois Grain Moth (*Sitotroga cerealella*, Ol.). The first insect is regarded as a secondary pest in that it usually attacks grain which has suffered previous damage. The two other insects are able to attack and reproduce in sound grain.

The Saw-toothed Grain Beetle.

An experiment on the control of this insect was carried out in large kali bottles, each containing 500 cc. of damaged wheat. The insecticides were enclosed in paper-muslin containers as in previous experiments. There were duplicate bottles of each treatment and into each 100 adult beetles were placed. The experiment was set up on 13.9.39 and allowed to incubate at 25°C. until 28.11.39 when an examination was made. The results are given in Table XII.

TABLE XII.

The Control of the Saw-toothed Grain Beetle (Oryzaephilus (Silvanus) surinamensis).

Treatments	Number of beetles inserted 13.9.39	Total number of beetles recovered 28.11.39
1. 0·5 grm. Mercury... ...	100	91
2. 4 grm. Zinc amalgam ...	100	87
3. Control (untreated) ...	100	2019

The figures show that a very effective control of this beetle was obtained with both mercury and zinc amalgam. In both these treatments many of the beetles recovered were dead; some had also disintegrated but their number could not be counted. A small percentage only had died in the untreated containers.

The Lesser Grain Borer.

An experiment on the control of this insect was carried out in small kali bottles each containing 250 cc. of undamaged wheat. Fifty adult grain borers were placed in each container. The insecticides used had all been employed previously in similar grain-pest experiments. The experiment was set up on 15.11.39 and the bottles stored at 25°C. until 20.2.40 when their contents were examined. The treatments carried out and the results obtained are shown in Table XIII. The figures are the average of duplicates of each treatment.

TABLE XIII.

The Control of the Lesser Grain Borer (Rhizopertha dominica).

Treatments	No. of borers inserted 15.11.39	No. of borers recovered 20.2.40			No. of grains damaged %
		alive	dead	total	
1. 5 grm. Mercury	50	11	39	50	0·5
2. 2 grm. Mercury	50	19	29	48	1
3. 1 grm. Mercury	50	33	15	48	1
4. 0·25 grm. Mercury	50	34	16	50	1
5. 0·125 grm. Mercury	50	34	14	48	2
6. 4 grm. Zinc amalgam	50	9	40	49	0·5
7. 2 grm. Zinc amalgam	50	7	43	50	1
8. 1 grm. Zinc amalgam	50	12	35	47	1
9. 0·5 grm. Zinc amalgam ...	50	11	37	48	0·5
10. 0·25 grm. Zinc amalgam ...	50	12	37	49	1
11. 8·3 grm. Tin amalgam ...	50	41	12	53	8
12. 5·8 grm. Calomel	50	27	20	47	4
13. 5 grm. Zinc	50	247	39	286	19
14. 5 grm. Corrosive Sublimate ...	50	201	34	235	18
15. Control	50	256	23	279	18
16. Control + empty containers ...	50	209	29	238	16
17. Control	0	0	0	0	0

Over the range of concentrations tested, both mercury and zinc amalgam appear to have been fully effective in preventing breeding. A similar control was given by calomel. In the presence of corrosive sublimate or zinc, however, reproduction proceeded as vigorously as in the controls. The efficacy of the various treatments can also be assessed from the condition of the grain in the different containers. Heavy insect infestations are seen to be associated with severe grain damage and *vice versa*. The longevity of the adult grain borer appears to be little affected by the various mercury treatments.

The Angoumois Grain Moth.

The efficacy of mercury for the control of this insect was tested in an experiment using large kali bottles, each holding 500 cc. of undamaged wheat. The appropriate weights of mercury for each treatment was enclosed in paper-muslin containers and buried in the grain. Immediately following this treatment, 40 living grain moths were placed in each bottle. The experiment was set up on 12.10.39 and the bottles kept at room temperature until 29.1.40, when an examination of their contents was made. The treatments carried out and the results obtained are shown in Table XIV. The figures given are the average of duplicates of each treatment.

TABLE XIV.

The Control of the Angoumois Grain Moth (Sitotroga cerealella).

Treatments	No. of moths inserted 12.10.39	Total moths and larvae recovered 29.1.40	Condition of grain 29.1.40
1. 2 grm. Mercury	40	40	Undamaged
2. 1 grm. Mercury	40	39	Undamaged
3. 0·5 grm. Mercury	40	40	Undamaged
4. 0·25 grm. Mercury	40	54	Slight damage
5. 0·125 grm. Mercury	40	365	Much damage, top 4 in. grain soft, caked and badly moulded
6. Control (untreated)	40	519	

At the time of examination breeding was proceeding actively in treatments 5 and 6, adults, larvae and pupae being prevalent in all containers. In the remaining treatments, however, no living individuals, mature or immature, were found. At the higher concentrations (treatments 1, 2 and 3) mercury is seen to have been fully effective in preventing reproduction. A small increase occurred in treatment 4, but at the time of examination the colony had become extinct. Damage in treatments 5 and 6 was severe, but almost confined to the grain in the upper half of the containers, the moths being unable to penetrate deeply into the grain. No damage was sustained in the first three treatments.

The value of mercury for the prevention of further deterioration of insect-infested grain was also tested. Equal weights of white-tooth maize, substantially infested with grain moth (*Sitotroga cerealella*), were placed in two wooden boxes. Each had a capacity of about 240 cubic inches and was fitted with a wooden top. About 30 grm. of mercury was placed in a small cardboard box with a perforated top and buried in the grain of one container. The other remained untreated and both were stored at room temperature. After six months no adult moths emerged in the treated container. In the other box reproduction continued unabated. In an examination carried out twelve months after the start of the experiment the total number of moths recovered from the treated and untreated containers was 3,500 and 9,100 respectively. Breeding in the treated grain had apparently ceased as no immature stages could be found ; in the other container, however, these were abundant. This restriction of breeding was accompanied by a much lower degree of damage to the grain.

5. Mode of Action.

Of the mercurials used in these experiments, those which have proved effective have one property in common. They emit a vapour which is composed, in part at least, of free mercury. Mercury vapour is readily detected by gold leaf, which tarnishes in its presence. Tests, in which gold leaf was placed in closed containers with metallic mercury, zinc amalgam and calomel, showed that tarnishing occurred with all of them and that it was most rapid in the presence of metallic mercury and least so with calomel. Reference to previous experiments will show that these three chemicals stand in the same order in respect of their effectiveness for the control of the grain weevil.

The behaviour of the adult insects in the mercurial treatments appeared to be in no way abnormal, pairing and oviposition were observed to occur with about equal frequency in both treated and untreated containers. Furthermore, the results indicate that neither the viability nor the subsequent reproductive capacity of the adults were adversely influenced by a period of storage in mercury vapour. Certain tests, however, have shown that mercury vapour is very toxic to the eggs of the grain moth (*Sitotroga cerealella*). When subjected to the vapour, the eggs shrivel, lose their colour and fail to hatch. Groups of eggs in this condition were found in the mercury-treated containers in the experiments on this pest previously described. The eggs of the grain weevil (*Calandra granaria*) appear to be similarly affected. Examination of infected grain in which reproduction had been prevented by the presence of mercury showed that weevil eggs were quite abundant. Very few, however, were of a normal creamy colour or turgid, the vast majority being brownish, much shrivelled or completely collapsed.

The results obtained in experiment 6 (bin experiment) showed that the efficiency of a given weight of mercury could be increased by subdivision ; a process which increases its total surface area. As vaporisation takes place from the surface of the globules, its rate will increase as the total surface area is increased. The time taken to build up a given concentration of mercury vapour in an enclosed space will therefore decrease as the surface area of the mercury is increased, other conditions being constant. To prevent breeding in a sample of grain, a toxic concentration of the vapour should be built up as quickly as possible in all parts of the sample. This can be achieved by using a large surface of mercury and by placing it at different levels in the grain to facilitate the process of diffusion. Mercury in a fine state of subdivision and incorporated in a porous base was used in experiment 8 and proved highly effective. Specimen samples of this mixture, made up into the form of " bricks," similar in dimensions to the familiar baked clay bricks, have been obtained. These are hard porous structures and tests have shown that mercury vapour is emitted by them at a high rate. It is envisaged that, in treating bulk samples of grain, such " bricks " could be fixed to the walls of the store-chamber. Here contact with the grain would be prevented by a suitable meshwork container. The optimum size, number and disposition of such bricks in the chamber could be determined by further experimental work. It is anticipated that such bricks would have an active life of many months, probably considerably more than a year. Their renewal would be a relatively simple procedure.

Reference to Tables IV and XIII will show that the vapour of corrosive sublimate exerts no restraining effect upon the reproduction of either the grain weevil or the lesser grain borer. This inactivity appears to be correlated with an undissociated vapour, and in this respect its stands in marked contrast to calomel, the other chloride of mercury.

The addition of other metals to mercury to form amalgams lowers the vapour pressure of the mercury and therefore decreases its efficiency.

6. Contamination of the Grain by Mercury.

The possibility that grain stored in an atmosphere containing mercury vapour might become contaminated by it has to be considered. The vapour might be absorbed by the grain or, more probably, condense as a film on its surface. As mercury is very toxic to biological systems, it is most probable that its absorption would adversely affect the viability of the grain. In tests carried out on grain stored for eleven months in mercury vapour, this was not found to occur.

The sensitivity of cultures of the grain weevil to the presence of mercury has been utilised to indicate the presence of such contamination. In one experiment samples of wheat were stored in large kali bottles with mercury. After three months the mercury was removed and the grain then infected with adult weevils. In certain cases the grain was removed from the bottles and exposed before infection. Details of these treatments and the results obtained are shown in Table XV.

TABLE XV.

The Effect of Mercury Residues on the Breeding of Calandra granaria.

Treatment before infection		Number of weevils inserted 15.12.39	Number of weevils recovered 26.2.40
1. Mercury removed, grain not exposed	(*a*)	100	1407
	(*b*)	100	1248
2. Mercury removed, grain exposed for 1 hour at room temperature (63°F.)...	(*a*)	100	1331
	(*b*)	100	781
3. Mercury removed, grain exposed for 1 hour at 83°F.	(*a*)	100	1220
	(*b*)	100	251
4. Control (untreated)	(*a*)	100	1641
	(*b*)	100	1648

Anomalous results were given by treatments 2b and 3b. It is probable that these were due to an escape of liquid mercury from the paper-muslin containers. This has been observed to happen occasionally in other experiments and could be eliminated by using less fragile containers. With these exceptions, reproduction in the treated samples proceeded vigorously. The final numbers of weevils produced, however, were slightly lower than in the untreated samples. As much variation normally exists in the number of weevils recovered from different containers of the same treatment, further experiments will be needed to determine the significance of the above differences.

Tests for the presence of mercury in the grain were also carried out with the aid of a spectrograph. Two samples of wheat were used, one had been kept in mercury vapour at room temperature for seven months, the other was untreated but stored otherwise under similar conditions. Tests were made upon grain taken direct from the containers. No mercury lines were found in the spectrograms of either samples. The sensitivity of the method was such that 1 mgrm. of mercury could be detected in 55·2 grm. of grain. These results indicate that, if mercury was present in the treated grain, its concentration was less than 1 part in 55,200 parts of grain.

7. Summary.

The Indian custom of placing metallic mercury with the grain in the storage container to prevent infestation by insects has been investigated. It is found to have a sound scientific basis as the presence of mercury prevents the reproduction of certain of these pests.

Experiments showed that the vapour of mercury was fully effective in preventing reproduction of the grain weevil (*Calandra granaria*), the saw-toothed grain beetle (*Oryzaephilus surinamensis*), the lesser grain borer (*Rhizopertha dominica*), and the Angoumois grain moth (*Sitotroga cerealella*).

Zinc and tin amalgams and calomel were less effective than metallic mercury.

The efficiency of a given weight of mercury is increased by subdivision, a process which increases its total surface area.

Mercury in a finely divided form, incorporated in a solid porous base, was found to be highly effective.

Those mercurials which proved effective were found to emit a vapour which contained free mercury.

Storage in mercury vapour was found to have no effect on the viability of adult grain weevils, neither did it affect their subsequent reproductive capacity.

The eggs of the grain weevil and those of the Angoumois grain moth were found to be very susceptible to mercury vapour and failed to hatch in its presence.

Germination and spectroscopic tests on grain stored for several months with mercury gave no indication that contamination had resulted. The grain weevil was able to breed vigorously in grain which had been so treated.

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THE MECHANISM OF ACTION OF A CONTACT INSECTICIDE.

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The object of this work is to throw light on the mechanism of the penetration of pyrethrum, the best known contact poison, into the body of an insect. It may be emphasised that pyrethrum, when used either as powder or liquid, acts very quickly on the insect, causing paralysis of the legs and of other parts of the body followed by death. The degree of the resistance exhibited by different insects against pyrethrum varies widely.

A large number of workers hold that before the insecticide can affect the nervous, respiratory or circulatory system of the insect, it must pass through the cuticle. It is thought that the variation in response to poisons between two species of insects is due to variation in the lipoid layer of the epicuticle. Among those who have accepted the theory of the permeability of insect cuticle are Hockenyos (1931), Hartzell & Wilcoxon (1932), Morozov (1935), O'Kane & others (1940), Hurst (1940), Wigglesworth (1941, 1942), Bredenkamp (1942), and Robinson (1942).

Wigglesworth (1941) failed to notice any increase in evaporation from *Rhodnius prolixus* paralysed with pyrethrum until after death, and found that in paralysed *Cimex lectularius* the spiracles were kept closed and still reacted to carbon dioxide. This led him to suppose that desiccation could not be held responsible as the main cause of death after pyrethrum poisoning. The same author (1942) from a study of the physiology of the cuticle brought out evidence in favour of the permeability of contact insecticides through the integument. His views agree with those of Bredenkamp (1942).

Roy, Ghosh & Chopra (1943) from experimental studies on the mechanism of the action of pyrethrum in the cockroach came to the conclusion that contact insecticides act through the spiracles. After gaining entrance through this route into the trachea, the pyrethrum is quickly eliminated into the body cavity through the tracheal wall.

Material and Methods.

The experiments were mostly performed on mosquitos, *Armigeres obturbans*, and some on house-flies and head-lice. The various preparations tested are given below :—

(1) Petroleum ether extract : saturated solution.

(2) Petroleum ether extract containing 0·12 per cent. by weight of pyrethrins I & II.

(3) Extract No. 2 + a few drops of oleic acid.

(4) Sulphuric ether extract : saturated solution + a few drops of oleic acid.

(5) Kerosene extract of the same strength as (2).

The penetration of fat in the insect body was demonstrated by cutting frozen sections 7–10μ thick, staining with Scharlach R, and counter staining with haematoxylin. The insects were fixed in 5 per cent. formaldehyde for 24 hours, washed in running water ; sections were cut from gelatine blocks.

The outlines of the three drawings, figs. 1, 2 and 3, were drawn with the aid of Camera lucida under 2/3rd objective and No. 2 eye-piece, whereas the tracheae were drawn under 1/6th objective. The dots represent fat cells stained by Scharlach R.

Pyrethrum painted on the Cuticle.

In order to be able to judge what part the cuticle plays in the entry of pyrethrum in an insect, all the above solutions were carefully applied on the last two or three abdominal segments of *Armigeres* by means of a fine pointed cotton-wool brush. The head and the thorax of the anaesthetised mosquito were placed on a saddle of plasticine in such a way that the tip of the abdomen lay on a glass slide and the rest of the insect rested on the plasticine in an inclined position. The insect was held in this position by fixing with plasticine. This greatly minimised the chance of the fluid running up along the body into the spiracles at the time of treatment with pyrethrum extracts. Although the application was repeated at least five times within a few seconds, yet the insects showed no signs of being affected by the poison.

Normally a very minute amount of pyrethrin is necessary to cause the death of an insect, and it is thought probable that if the cuticle normally allowed the entrance of pyrethrum into the body, death of the insect should have resulted from the absorption of a fair amount of pyrethrin present in the extract applied on the abdominal cuticle of the mosquito. It has been shown that as small a dose as 0·0017464 mg. of pyrethrins is sufficient to kill a single *A. obturbans*.

In other experiments the hind leg or legs alone of a living mosquito were placed in a drop of the insecticidal fluid under a cover-glass on a glass slide in such a way that the fluid was prevented from coming into contact with other parts of the body. No definite proof of the entry of pyrethrum was obtained when the legs were thus kept immersed in the fluid for 5 minutes.

Transverse sections of the femur and also of the abdomen when they were treated separately with solutions (3) and (4) failed to reveal the presence of oil globules underlying the cuticle.

During treatment of the last abdominal segments, some mosquitos succumbed to the toxic effect of the insecticide ; the cause of death was believed to be due to pyrethrum quickly running up along the surface of the body with the petroleum ether and thus reaching the inside of the trachea through the spiracle. This idea was substantiated by finding droplets of oil either inside or outside the tracheae in the thorax. Transverse sections of the abdomen on which the insecticide was directly applied failed to show the presence of oil. It may be stated that longitudinal sections of the abdomen in frozen specimens have not proved successful.

An extremely small shallow square trough was prepared with plasticine and fixed to the cuticle on the dorsum of the thorax of *Pediculus capitis*. Into this was placed a drop of kerosene-pyrethrum mixture. The trough was fixed to the cuticle in such a way that the fluid had no opportunity of coming into contact with any other part of the body. Loss of the fluid from evaporation was made good. At the end of 5 to 10 minutes the fluid was soaked up with filter paper and the plasticine was removed. The insect was watched for half an hour for signs of paralysis, which, however, did not occur in any of the specimens experimented upon.

It was therefore thought that pyrethrum dissolved even in a suitable medium was incapable of penetrating the healthy cuticle, and that the normal way by which it could enter the body was through the spiracle.

Pyrethrum sprayed on an Insect.

Additional evidence in support of the above contention, *i.e.*, that the pyrethrum normally enters through the spiracle, was afforded in specimens when they were sprayed with a mixture of petroleum ether and oleic acid. This mixture was first introduced in a closed chamber of 50 cubic feet air space by means of a De Vilbiss spray, the mosquitos being released immediately afterwards. Direct hits on any insect with the oleic acid mixture were thus avoided.

In frozen sections, droplets of oil were invariably found distributed in intimate association with the trachea, the oil being deposited either inside or outside the latter or in both these situations (fig. 1). The petroleum ether holding the oil in solution quickly escapes through the wall of the trachea by diffusion ; hence its appearance just outside it.

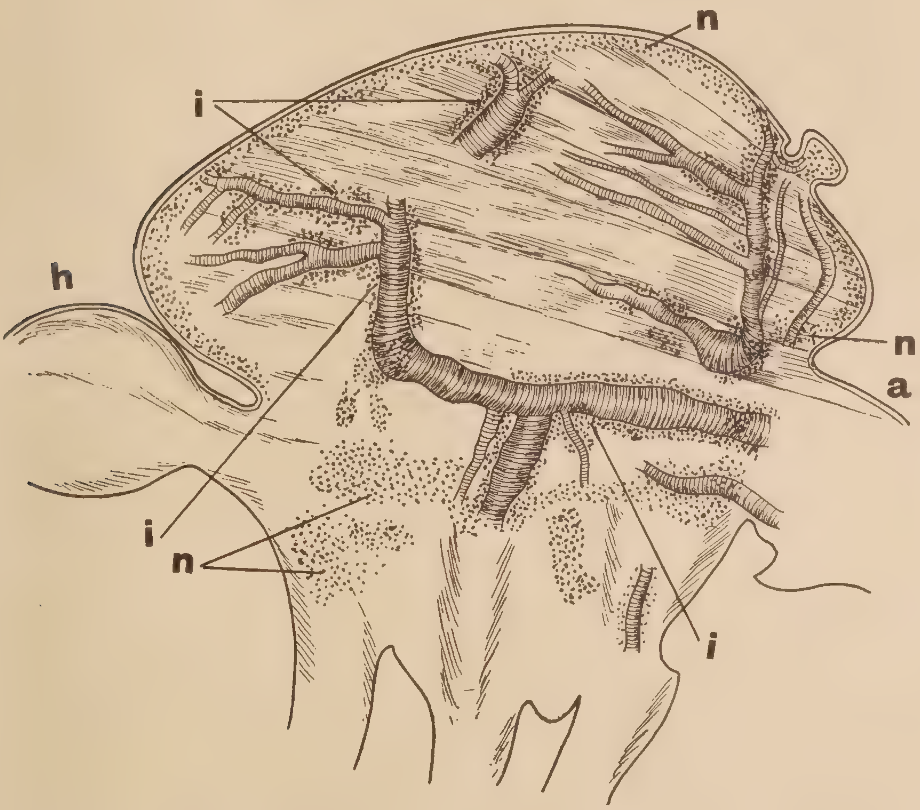

Fig. 1. Mosquito sprayed with pyrethrum extract and oleic acid : *h*, head ; *a*, abdomen ; *n*, fat cells ; *i*, fat introduced with pyrethrum extract deposited around tracheal trunks.

Certain peculiarities in the distribution of oil globules in the body of a mosquito or a fly after it has been sprayed with an oily mixture are worth noting ; these have a close bearing on the route taken by the oil in the body of the insect : (1) The oil is found in intimate association with the tracheal trunks ; (2) the droplets are deposited more outside large trunks than inside them ; (3) small branches seldom show any oil droplet outside them but sometimes they are filled with the oily fluid.

After spraying with a mixture of oleic acid and petroleum ether, a heavy accumulation of oil is noticed, particularly in certain places, *e.g.*, underlying nearly the whole of the cuticle of the dorsum of the thorax, neck, central parts of the thorax and near the junction of the thorax and abdomen. In a normal mosquito, fat droplets are similarly found in the same situation and it will not be possible to distinguish, from the above characters alone, a mosquito sprayed with an oily solution from a normal mosquito (fig. 2). It is therefore apparent that mere detection of oil globules underlying the cuticle of the dorsum of the thorax cannot be taken as a definite evidence of the quick passage of the insecticide through the cuticle.

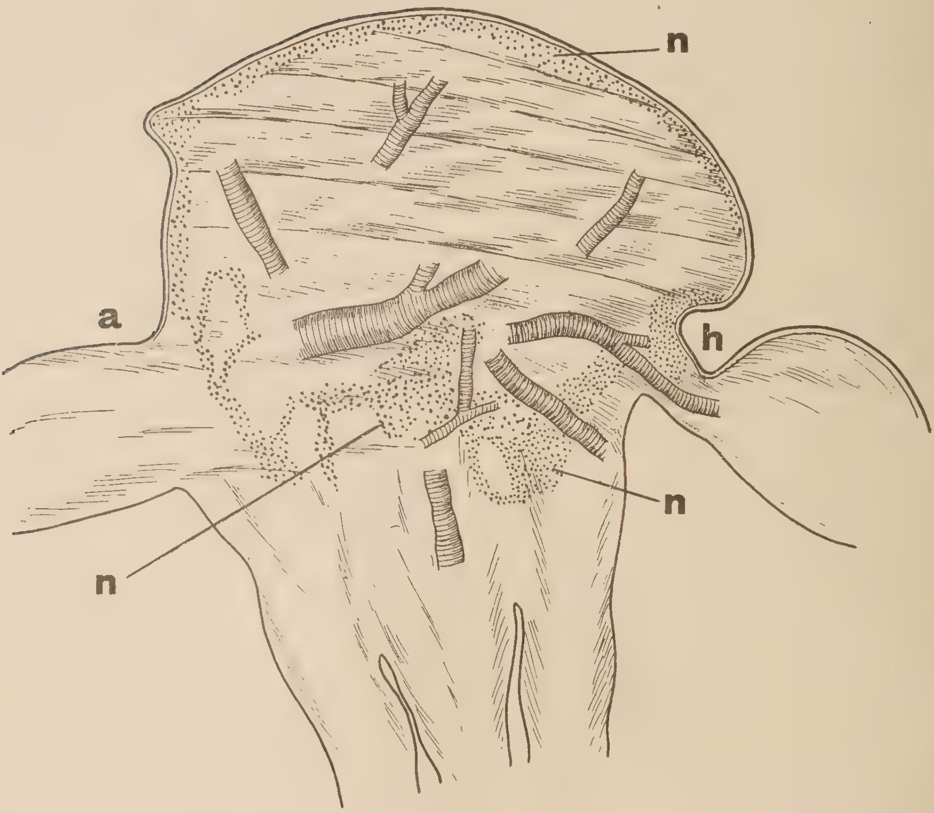

Fig. 2. The distribution of fat cells in the body of a normal mosquito : *h*, head ; *a*, abdomen ; *n*, fat cells.

It should be noted that in mosquitos sprayed with a mixture of petroleum ether and oil, oil droplets have never been noticed on muscles, but lying between two bands of muscles are sometimes seen small tracheal branches which are filled with the oily fluid.

It has already been stated that the oil is found in some specimens inside tracheal trunks, in others outside them, while in a third group of insects it is seen both inside and outside. An attempt was therefore made to find out the conditions that influence the deposition of oil in the body of the insect in the manner stated above.

When the insect has been allowed to imbibe the maximum amount of pyrethrin and correspondingly oil also, the greater part of the oil is found deposited just outside the large trunks, while fewer droplets are noticed here and there inside them. Under such conditions the small branches may contain oil, which is, however, seldom found outside them. When the dosage is small, the oil is always found outside the large trunks.

These facts indicate that the petroleum ether carrying the insecticide in solution quickly diffuses out through the tracheal wall, and that accumulation of oil inside the trachea takes place only when the power of diffusion is lost.

Penetration of the Oleic Acid in the Insect.

It has already been demonstrated that oleic acid in solution in either petroleum or sulphuric ether quickly diffuses out into the body cavity through the tracheal wall.

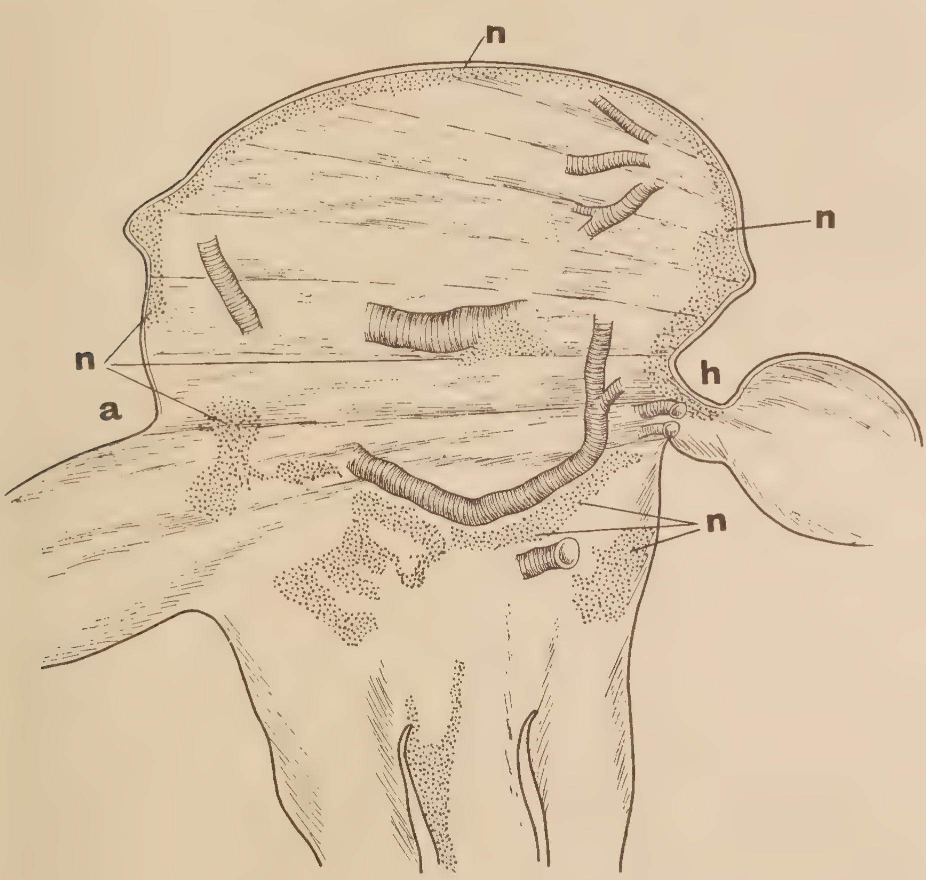

Fig. 3. Fat cells found in a mosquito after spraying with pure oleic acid : *h*, head ; *a*, abdomen ; *n*, fat cells.

When mosquitos are subjected to the action of oleic acid alone in a testing chamber, only a few are knocked down and it is seldom that any are actually killed. Sections of the thorax of a mosquito which has been sprayed with oleic acid do not present any difference from a normal mosquito in the disposition of the oil droplets in the body (fig. 3). This proves that the fine droplets of oleic acid discharged from a De Vilbiss spray are incapable of entering the trachea.

Entry of the Insecticide through Wing Veins.

After the mosquitos were heavily sprayed with pyrethrum extract and oil mixture, the wings were removed and washed in 5 per cent. formaldehyde. When stained with Scharlach R, the fat droplets were observed to be completely absent from the veins.

Resistance of Ticks to Pyrethrum Extract.

Ticks are extremely hardy, and it is believed that they are highly resistant to pyrethrum. An indication of how pyrethrum affects them will be obtained from Table I.

TABLE I.

Tick	Liquid preparation tested	Minimum time of immersion to cause death within 24 hrs.
Rhipicephalus sanguineus :	Pyrethrum extract in kerosene (pyrethrins 0·12% by wt.)	
Normal-sized male	,,	15–20 sec.
Medium-sized female... ...	,,	30 sec.
Large-sized female	,,	1 minute
Ornithodorus savignyi :		
Medium-sized adult	,,	30 sec.
Nymph	,,	2 sec.
Larva	,,	6 minutes immersion does not kill them.
,, ...	Kerosene oil	6 minutes immersion does not affect them.

The above results show that larvae of *O. savignyi* when dipped in the pyrethrum-kerosene solution for 6 minutes are not affected within 24 hours.

The Effect of Pyrethrum on Insects with their Spiracles closed.

In order to prove conclusively that pyrethrum enters through the spiracles only and not through other parts of the body such as the integument or the wings, it is necessary to close the spiracles and demonstrate that pyrethrum is ineffective in causing the death of the insect under such conditions. We chose the common bluebottle fly, *Chrysomyia megacephala*, for this purpose, this fly being extremely susceptible to pyrethrum. We succeeded in temporarily sealing all its four spiracles (anterior and posterior thoracic) with paraffin solidifying at about 46–48°C. The insect is able to live for 8 mins. 54 secs. on an average (6 specimens examined) (maximum 15 mins. 10 secs., minimum 6 mins. 15 secs.) in this state, though in some cases the sealing is imperfect and the fly can survive much longer.

The effect of pyrethrum on flies with closed spiracles is shown in Table II.

The difference in the time of death of a normal fly and of a fly in which the spiracular openings have been closed with soft paraffin is very striking. The paraffin seal definitely acts as a barrier against the pyrethrum entering the respiratory tubes. This accounts for the delayed action observed in experimental flies when exposed to pyrethrum spray.

TABLE II.

Comparison of the actions of pyrethrum on a normal fly and on a fly in which the spiracular openings have been closed with soft paraffin.

Expt. No.	Method of administration of pyrethrin	Time of death		Difference
		Test fly	Control fly	
		min. sec.	min. sec.	min. sec.
1	Sprayed only once in a closed chamber	3 45	2 33	1 12
2	,, ,, ,, ,,	6 45	5 2	1 43
3	,, ,, ,, ,,	14 0	9 45	4 15
4	Spraying was continuous till one of the flies died	5 35	0 55	4 40
5	,, ,, ,, ,,	13 45	0 35	13 10
6	,, ,, ,, ,,	5 57	1 35	4 22
7	,, ,, ,, ,,	8 40	0 45	7 55
8	,, ,, ,, ,,	9 4	1 30	7 34
9	,, ,, ,, ,,	7 48	1 50	5 58
10	,, ,, ,, ,,	38 1	0 25	37 36
11	,, ,, ,, ,,	Lived over 2 hours	0 30	Over 2 hours

Entry of Pyrethrum Dust into the Body of the Insect.

Although a large amount of work has been done to determine by what route the fluid insecticide enters the body, attempts have been made only by Roy, Ghosh & Chopra (1943) to demonstrate how a contact insecticide such as pyrethrum in the powdered state can act on the insect. It was shown by these authors on the cockroach that the route followed by the dust was the same as the liquid.

If the spiracles are closed and if the method as used with the liquid insecticide is adopted, it can also be easily demonstrated that there is no difference between the powder and the liquid insecticide in the method of their penetration into the body of the insect.

After closing the spiracles in *C. megacephala*, the insect is liberally dusted with pyrethrum powder on every part of its body. When such an insect is compared with a control fly which has also been similarly treated with the pyrethrum dust, signs of poisoning are always found appearing early in the latter but seldom in the former. Flies with incompletely closed spiracles may even live for hours without showing any signs of paralysis of the legs. When the seal is removed from one of the anterior spiracles and the latter is touched with the powder, inability to walk is noticed within 5 to 10 mins., and the death of the insect takes place within 3 hours. When one of the posterior spiracles is similarly treated; the weakness of the legs is noticed within 3 mins. and death occurs within 2 hours.

While pyrethrum dust really produces the characteristic effects on tracheate insects, it has no injurious effects on atracheate animals. Contact of larvae of *O. savignyi*, both in their early and late larval stages, even for 24 hours with pyrethrum dust did not seem to produce any injurious effects on the life of these creatures, while both nymphs and adults of this species were quickly affected by the dust.

Discussion.

It is possible that pyrethrum extract can enter the body of an insect through the cuticle, wing veins, spiracles and the mouth.

Roy, Ghosh & Chopra (1943) have pointed out that pyrethrum dust mixed with sugar when ingested by a cockroach is totally innocuous to them.

It is natural to presume that the wing veins, particularly when they are damaged, would allow the passage of pyrethrum but the experimental results indicate that they do not.

All evidence on the penetration of the insecticide through the cuticle, except that collected by Robinson (1942) and Wigglesworth (1942), has been based on studies made especially on dead cuticle ; therefore the experiments cannot be regarded as having been performed under natural conditions.

Robinson (1942) noticed that the inert larvae of *Ornithodorus moubata* in their early larval life were stimulated into activity so that they moved their legs to and fro when immersed in a solution of pyrethrum. This was accepted by him as a sure indication of the entry of the insecticide through the cuticle on account of the absence of spiracles and tracheal system in the larvae ; also the mouth and anus are non-functional. But if the above suggestion of the entry of the poison into the body is accepted, it will not be easy to explain the fact that immersion of larvae in a solution containing 0·15 per cent. by wt. pyrethrin I for 3 hours was found not to affect them adversely.

The relative degrees of tolerance to pyrethrum exhibited by *O. moubata* and *O. savignyi* in the different stages of their lives are not known. One might, however, expect that larvae of both species would show less tolerance to pyrethrum than do nymphs or adults. The noteworthy feature is that immersion of larvae of *O. savignyi* in pyrethrum extract for 6 minutes does not affect them. Larvae of *O. savignyi*, like those of *O. moubata*, are without spiracles and tracheal system, and the mouth and the anus are non-functional (Christophers, 1906). When the effects of immersion of adult *O. savignyi* are compared with those seen in larvae, it seems doubtful if pyrethrum kills insects by entering the body through the cuticle. Robinson also did not encounter any signs of poisoning in larvae of *O. moubata* when immersed in pyrethrin extract for 3 minutes.

Later, Wigglesworth (1942) succeeded in demonstrating the passage of the insecticide through the cuticle of *Rhodnius* by establishing a prolonged contact for hours between the insecticide and the cuticle of living 5th stage nymphs. He noticed the occurrence of paralysis which, however, did not ensue within 2 hours. All contact poisons act extremely quickly, and when this prolonged latent period is taken into consideration, one would be justified in holding that the " normal " route of the penetration of the insecticide is not through the cuticle.

It is true that under certain conditions the insect cuticle may act as a permeable membrane, but such experiments, though interesting for the light which they throw on the permeability of this structure, do not really offer any practical means of explaining how the rapid death of an insect is brought about by pyrethrum, used either as liquid or dust.

The mosquitos in our experiments were sprayed with a mixture of petroleum ether, extract of pyrethrum and a drop of oleic acid ; the penetration of oil and *pari passu* of the insecticide was demonstrated in the body of the insect by staining methods. The results indicated that the spiracles and not the cuticle allowed the passage of the insecticide first into the trachea and thereafter into the body cavity of the insect. The fact that the oil is invariably found around large tracheal trunks when the insect has been sprayed with a suitable oily solution, is in favour of the occurrence of rapid diffusion of the insecticide through the tracheal wall.

The distribution of oil droplets in intimate relation with tracheal trunks is a constant and at the same time a striking phenomenon. The presence of oil under the cuticle of the thorax must be regarded as a normal feature and is of no value as evidence that the insect cuticle allows the quick passage of the insecticide.

Whether or not it is possible to seal the spiracles hermetically is a point which is outside our enquiry. But the results obtained after the application of pyrethrum on insects in which the spiracular openings have been closed with paraffin clearly show that under such conditions the death of the fly takes place considerably later than in a normal fly. This will serve as additional evidence in support of our contention that the entry of the insecticide is effected not through the cuticle but through the respiratory channels. The rapid diffusion of the insecticide into the body cavity therefore forms the principal basis that determines the mechanism of the action of all contact insecticides, such as pyrethrum, on insects in general that possess a tracheal system, and of kerosene oil on mosquito larvae.

Summary.

In order to determine the method of entry of a contact insecticide such as pyrethrum into the body of an insect, studies were undertaken which showed that :—

(*a*) The rapid penetration of the insecticide into the body cannot be effected through the cuticle.

(*b*) When a mosquito has been sprayed with a mixture of pyrethrum extract and oleic acid, the deposition of fat globules around the tracheal trunks is a characteristic feature ; this suggests that rapid diffusion of the insecticide takes place through the tracheal wall.

(*c*) Experiments on flies with their spiracles closed indicate that the absorption of pyrethrum, either in the liquid and powdered states, was very slow. This fact indicates that normally pyrethrum enters the body through the spiracle.

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NEW AND LITTLE KNOWN WEST AFRICAN MIRIDAE (CAPSIDAE) (HEMIPTERA HETEROPTERA).

By W. E. China, M.A., F.R.E.S.

The following descriptions are based on material collected by Mr. H. E. Box in the Gold Coast, during his work on insect pests of the cocoa plantations, and submitted to me for identification by the Imperial Institute of Entomology. Owing to war-time difficulties in obtaining various scientific journals, it is not always possible to make certain that a species is undescribed, so that although Mr. Box has collected several others which may be new, they have not been described here for that reason. The species now dealt with, however, are of particular interest either from the point of view of new distribution or from remarkable structure or striking colouration. Type specimens are preserved in the British Museum.

Family Miridae.

Subfamily Mirinae.

Deraeocoris ostentans, Stål, **nigroruber,** var. nov.

Head shining black with a short longitudinal line in front and a transverse line at base of vertex, yellowish white; antennae fulvous with apex of first segment, whole of second in male and base and apex of second in female, apex of third and whole of fourth segments, black or dark brown, second segment of male distinctly thickened throughout; rostrum black. Pronotum shining black with scattered fine punctures, anterior collar and posterior lateral angles narrowly, whitish. Female with a yellowish white triangular spot anteriorly in middle and a smaller one in middle of posterior margin. Pro-, meso- and meta-sterna and pleura, also coxae, black, the margins of the propleura and prosterna and the metasternal orifices, yellowish white. Scutellum shining black without punctures. Hemielytra shining with scattered punctures becoming evanescent on apical half of corium; clavus and base of corium black; inner apical angle of corium, behind apex of clavus, dark brown, this brown area more extensive in male than in female in which it forms a more or less distinct spot, apex of cuneus dark brown to black; remainder of corium and cuneus bright blood red. Membrane smoky hyaline with the usual brown band along apices of cells and the broader brown arcuate band before apex of membrane. Femora fulvous orange, tibiae yellowish white with extreme base and two rings dark brown to black; tarsi yellowish white with apical segment and claws dark brown. Venter sanguineous with genital segments dark brown to black.

Habitat: Gold Coast, Tafo, 2♂♂, 2♀♀, 21.xii. 1942 (*H. E. Box*, Coll. No. H. 123).

This very strikingly coloured variety appears at first sight to be a distinct species with a neater, more convex, shining body. There appears to be no doubt, however, that it is specifically identical with *D. ostentans*, Stål, a very variable species widely distributed over the Ethiopian region.

Subfamily Bryocorinae.

This remarkable subfamily contains a number of species of economic importance both in Asia and Africa. The African genera and species were dealt with by Poppius in his "Die Miriden der Äthiopischen Region" 1, 1912, and 2, 1914, in which great work he listed 13 African and Mascarene genera. In 1927, Schumacher (S. B. Ges. naturf. Freunde Berlin, **1917,** pp. 447–453) established three more Ethiopian genera of this sub-family, *Pantilioforma* with type *P. impressopunctata*, Schum., *Mandragora* with type *M. venefica*, Schum., and *Bryocoropsis* with type *B. laticollis*, Schum., all from Spanish Guinea. In 1922, Bergroth (Rev. zool. afr., **10,** pp. 51–61) published an annotated list of the African Bryocorinae in which he sunk *Mandragora*, Schum., as a synonym of *Physophoropterella*, Popp., and added two additional genera, *Tetanophleps*, Bergroth, a new genus with type *T. gibbifrons*, Bergr., and *Sthenarusoides*, Distant, transferred by Bergroth from the Phylinae to the Bryocorinae under the emended name *Sthenaroides* (type *S. montanus*, Dist.). In this paper Bergroth brought forward two queries which can be settled here. *Eucerocoris westwoodi*, White 1842 (Trans. ent. Soc. London, **3,** p. 94) described from Africa (Guinea) was queried as a *species incerti generis*. Poppius had placed this species in *Helopeltis*, but Bergroth was of the opinion that White could not possibly have overlooked the pin-like scutellar spine. However, the type is in the British Museum and it is definitely a *Helopeltis*, in fact it is identical with *H. alluaudi*, Reuter 1905, over which it takes priority. White must have overlooked the scutellar spine which is present in the type specimen. Bergroth also pointed out that *Lycidocoris thoracicus*, Distant, was probably generically distinct from *Lycidocoris*, Reuter & Poppius. I have studied this species and agree with Bergroth ; indeed *L. modestus*, Dist., is also doubtfully congeneric with *Lycidocoris* and on page 179 of this paper I have transferred both these species to the genus *Pantilioforma*, Schumacher. A careful study of Bergroth's description of *Tetanophleps* also convinces me that this genus is synonymous with *Arculanus*, Dist., the genotype of which is in the British Museum, and must fall as a synonym of Distant's genus.

Since Bergroth's 1922 list, two other important papers on African Bryocorinae have been published, Ghesquière's " Notice monographique sur les *Helopeltis* Sign. (Miridae) éthiopiens " (Rev. zool. afr., **10,** pp. 281–300, 1922) in which two new species and a number of new varieties of *Helopeltis* were described and Schouteden's " *Sahlbergiella* nouveaux du Congo Belge " (Rev. Zool. Bot. afr., **26,** pp. 473–476, 1935) in which four new species of *Sahlbergella* (*sens. lat.*) were described.

Bergroth 1922 listed 17 African and Mascarene genera. Recent collecting by Mr. H. E. Box in the Gold Coast has helped to add five more, *viz.*,

Poppiusia, gen. n. (type *P. combretorum*, sp. n.).

Boxia, China (type *B. khayae*, China (Bull. ent. Res., **34,** pp. 287–290, 1943).

Idioaspis, gen. n. (type *I. macarangae*, sp. n.).

Stenopterocoris, gen. n. (type *S. laticeps*, sp. n.).

Distantiella, gen. n., for *Sahlbergella theobroma*, Distant.

These would bring the total number of Ethiopian and Mascarene genera to 22, but the sinking of *Tetanophleps*, Bergr. 1922, as a synonym of *Arculanus*, Distant 1904, in the present paper reduces the total number of genera to 21.*

In the following key to these 21 genera, I have attempted to avoid the use of antennal characters as a primary distinction since antennae are so frequently broken off in material to be determined.

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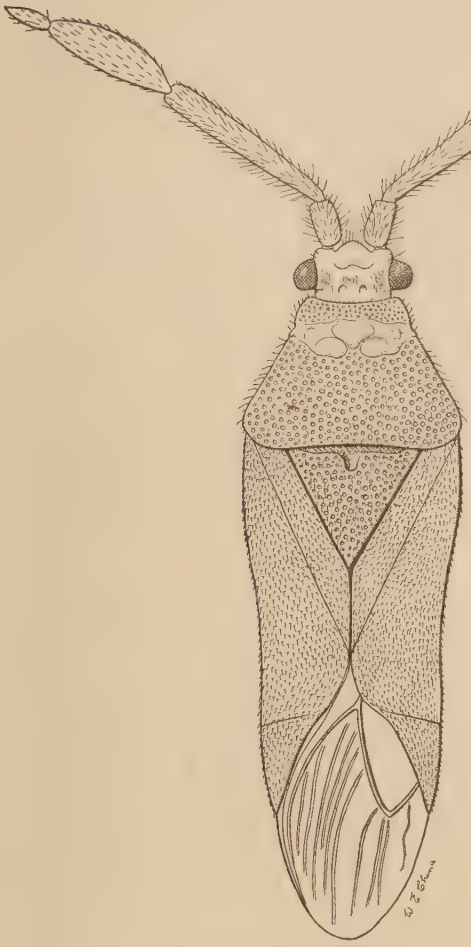
* The Bryocorinid genus *Monalocoris*, Dahlbom 1850, is represented in Madeira by *M. parvulus*, Reut.

Key to the African and Mascarene Genera of the Subfamily BRYOCORINAE.

1. Membrane of hemielytron with a number of auxiliary veins or vein-like impressions extending from basal cell to apex of membrane (as in Coreidae) in addition to the well marked vein (cubitus) arising from the basal angle of the cell and extending along anal margin (fig. 1)..................................2



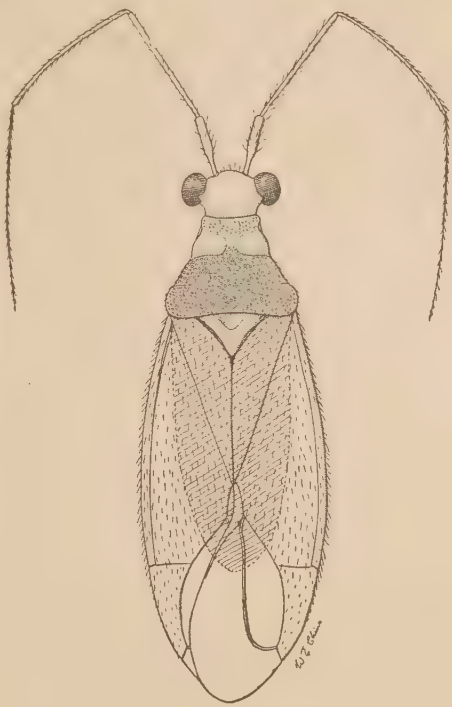


Fig. 1. *Pantilioforma impressopunctata,* Schumacher, fide China.

Fig. 2. *Prodromus thaliae,* sp. nov. ♀.

Outline to show structure and pubescence (legs omitted).

Membrane of hemielytron without such auxiliary veins, sometimes with a single vein arising from the apical angle of the basal cell (*Arculanus,* Dist.)...3

2. Frons distinctly swollen and produced anteriorly between bases of first antennal segments, delimited from vertex by a sinuate impression, first antennal segment short and thick, shorter than length of head with neck, twice as long as wide ; third segment very strongly thickened in middle, much thicker than first segment (fig. 1)......*Pantilioforma,* Schum. 1917. Type *P. impressopunctata,* Schum. 1917

Frons feebly swollen and not produced anteriorly between bases of antennae; not delimited from vertex by a sinuate impression, first antennal segment less thickened, slightly longer than length of head with neck, four times as long as wide, third segment not much thicker in middle than apex of second segment......*Lycidocoris*, Reut. & Popp. 1911. Type *L. mimeticus*, R. & P. 1911 Wr. wp.

3. Scutellum armed with one or more erect spines or spine-like processes 4
Scutellum unarmed 5

4. Scutellum small, with a single long slender spine ending in a button-like knob; antennae long and slender throughout.. Wr. wp.
Helopeltis, Sign. 1858. Type *H. antonii*, Sign. 1858 (=*Aspicellus*, No. Costa 1864)

Scutellum distinctly swollen, with a pair of short pointed spurs; antennae with the apices of first three segments strongly inflated or clubbed .... *Physophoropterella*, Popp. 1914. (=*Mandragora*, Schum. 1917). Type *P. bondroiti*, Popp. 1914 No.

5. Apex of corium, above base of cuneus, raised in a shield-shaped elevation...... *Physophoroptera*, Popp. 1910. Type *P. mirabilis*, Popp. 1910 No.

Apex of corium without a shield-shaped elevation.................................6

6. Frons in front with three strong anteriorly or upwardly directed spines; first antennal segment densely beset with long erect hairs or scale-like hairs......7

Frons without three such spines, sometimes with two tubercular processes in which case first antennal segment without hairs or only sparsely hairy......8

7.* Last three antennal segments with long erect hairs; femora with long hairs, body above not granulate......*Chamus*, Dist. 1904. Type *C. wealei*, Dist. 1904 No

Last three antennal segments almost without hairs; femora without hairs; body above granulate......*Chamopsis*, Reut. & Popp. 1911. Type *C. conradti*, R. & P. 1911 No

8. Embolium (costal cell) distinct, percurrent to base of cuneus, narrow, sometimes very narrow (*Prodromus*) parallel sided; sometimes suddenly widened at apex (*Felisacus*) in which case antennae slender and scutellum simple.........9

Embolium less distinct, not percurrent to base of cuneus, broader, widening from base to apex (fig. 6)...14

9. Embolial and claval sutures both with a row of close set punctures (high magnification) (figs. 4, 5)...12

Embolial and claval sutures devoid of punctures (figs. 2, 3) 10

10. Claval vein distinct usually with a row of punctures; eyes seen from above circular; corium hyaline............*Felisacus*, Dist. 1904. Type *Liocoris glabratus*, Motsch. 1863 (=*Liocoris*, Motsch. 1863 *nec* Fieb. 1859) (=*Hyaloscytus*, Reuter 1904) No

Claval vein indistinct or absent, without punctures; eyes seen from above distinctly longer than wide; corium sometimes translucent but not hyaline... 11

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* See note under *Chamus boxi*, sp. nov. page 181.

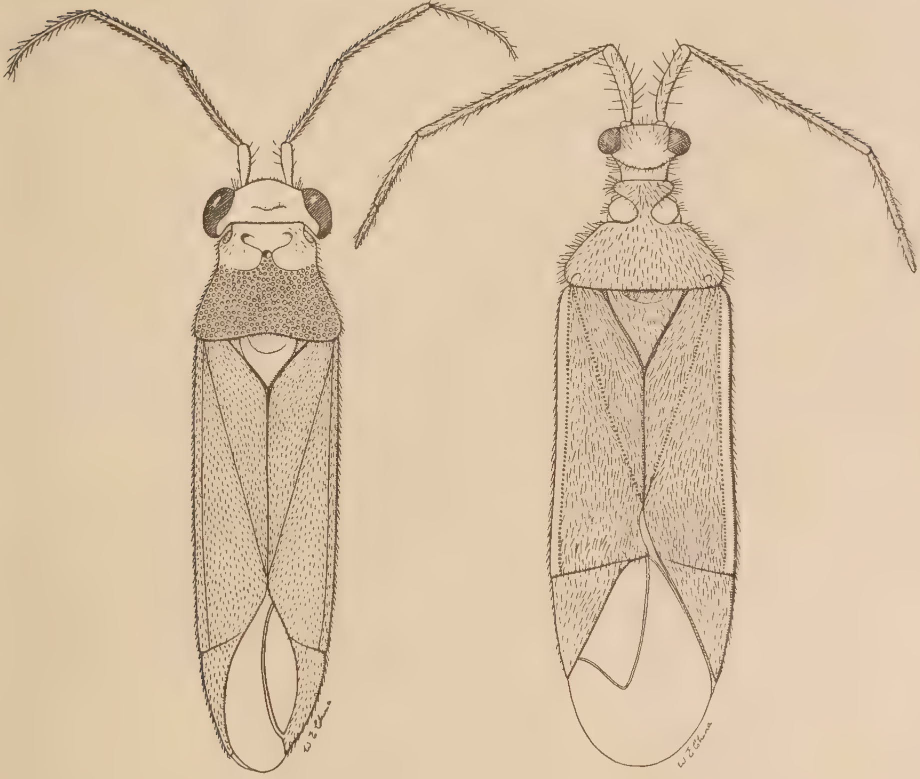

Fig. 3. *Stenopterocoris laticeps,* gen. et sp. nov. ♂.

Fig. 4. *Poppiusia combretorum,* gen. et sp. nov. ♂.

Outline to show structure and pubescence (legs omitted).

11. Head behind eyes narrowed to form a distinct neck, so that the posterior margin of eyes is well in front of anterior margin of pronotum ; costal margins of hemielytra convexly curved (fig. 2)........................ *Prodromus,* Dist. 1904
Type *P. subflavus,* Dist. 1904

Head without a neck, the eyes contiguous with and extending posteriorly beyond anterior lateral angles of pronotum ; costal margins of hemielytra straight, parallel sided (fig. 3).........*Stenopterocoris,* **gen. nov.** Type *S. laticeps,* **sp. nov.**

12. Pronotum strongly wrinkled.............................. *Pararculanus,* Popp. 1912
Type *P. piperis,* Popp. 1912

Pronotum smooth and shining..13

13. Frons strongly swollen, as seen from above, produced well in front of eyes above base of clypeus, first antennal segment strongly thickened but without hairs ; membrane cell with a supernumerary vein extending from its apical angle to apex of membrane......*Arculanus,* Dist. 1904 (=*Tetanophleps,* Bergr. 1922).
Type *A. marshalli,* Dist. 1904

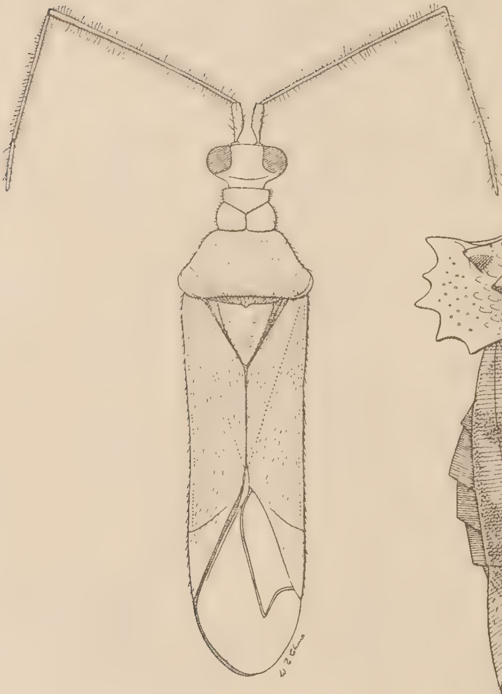

Fig. 5. *Pachypeltis humeralis*, Walker, ♂. Outline to show structure and pubescence (legs omitted).

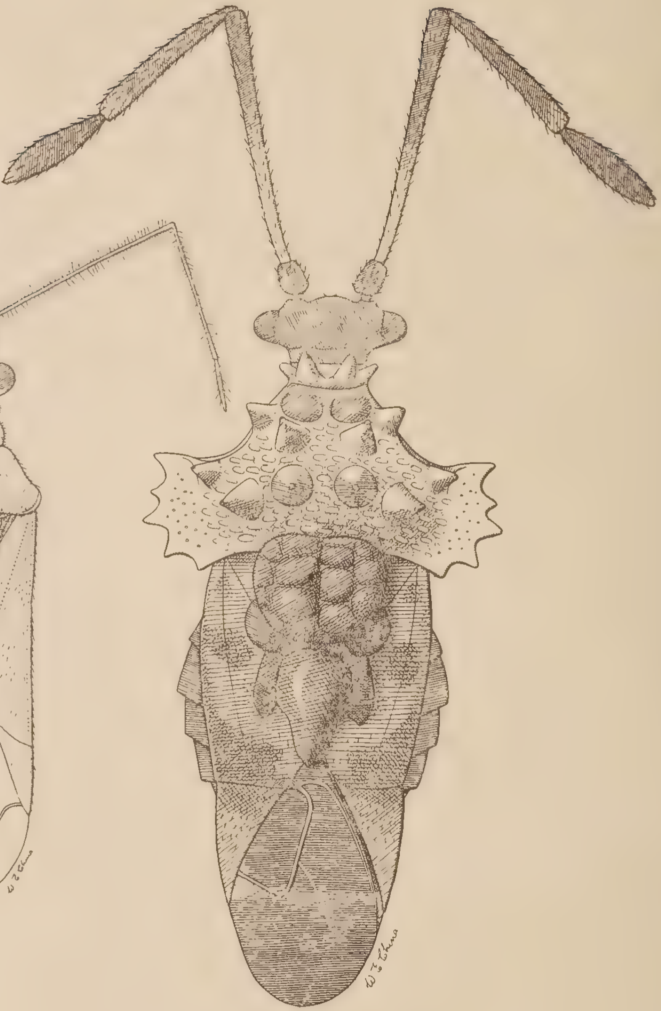

Fig. 6. *Idioaspis macarangae*, gen. et sp. nov. Outline shaded to show structure, pubescence and colour pattern (legs omitted).

Frons not swollen nor produced in front of eyes above base of clypeus, anterior margin seen from above almost straight between and level with anterior margins of eyes; first antennal segment not inordinately thickened, with long erect hairs; membrane cell without a supernumerary vein extending from its apical angle to apex of membrane (fig. 4)......*Poppiusia*, **gen. nov.**
Type *P. combretorum*, **sp. nov.**

14. First antennal segment much longer than broad, as long as head seen from above; vertex posteriorly carinate (as in many species of *Lygus*), small species *circa* 3 mm..15

First antennal segment about as broad as long, much shorter than head seen from above ; vertex posteriorly not carinate ; larger species 5 mm. or more 16

15.* Pronotum and hemielytra distinctly though finely and rather sparsely punctate ....*Sthenarusoides*, Dist. 1913 (=*Sthenaroides*, Bergr. 1922). Type *S. montanus*, Dist. 1913

Pronotum and hemielytra not punctate...........*Monalocoropsis*, Popp. 1912 Type *M. madagascariensis*, Popp. 1912

16. Frons, above base of clypeus between antennae, with a pair of distinct conical protuberances, these rarely minute or fused into one in which case apex of second and the third and fourth antennal segments strongly swollen ; sometimes tubercles minute and setigerous and rather indistinct in which case pronotum, posterio-laterally, strongly dilated, its margin serrate and pronotal collar armed with four tubercular processes (fig. 6) 17

Frons, above base of clypeus between antennae without a pair of conical protuberances or setigerous tubercles, the frons sometimes prominent between antennae in which case apex of second antennal segment not or only slightly thickened 20

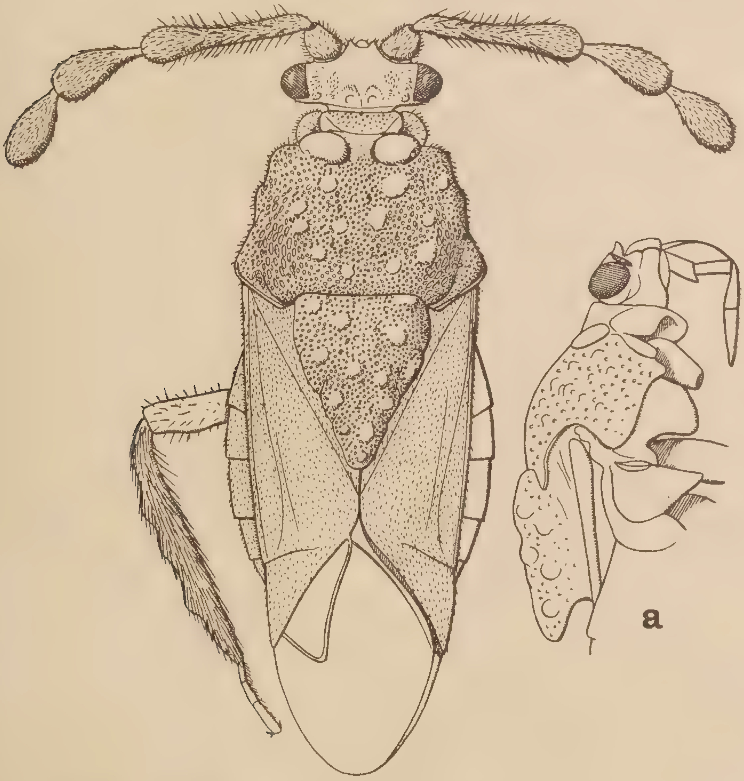

Fig. 7. *Distantiella theobroma*, Distant. Outline to show structure and pubescence ; only one hind leg shown to indicate presence of nodular swellings on tibia. *a*, lateral view of head and thorax.

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[*] I have not seen *Monalocoropsis*, Popp., and the differential characters here are based on Poppius' description. It is possible that these two genera are synonymous.

17. Pronotal collar with 4 erect tubercular processes, the inner pair elongate; surface of pronotum with 10 erect conical processes in two rows, the two centre ones of posterior row of 6, much longer and bigger than others; posterior lateral margins of pronotum dilated and serrate; scutellum split up into 6 lobes (fig. 6) ......*Idioaspis*, **gen. nov.** Type *I. macarangae*, **sp. nov.**

Pronotal collar without erect tubercular processes; surface of pronotum strongly punctate without erect conical processes arranged regularly but sometimes with irregular scattered tubercles of moderate elevation in which case posterior-lateral margins of pronotum not serrate and scutellum not multi-lobate 18

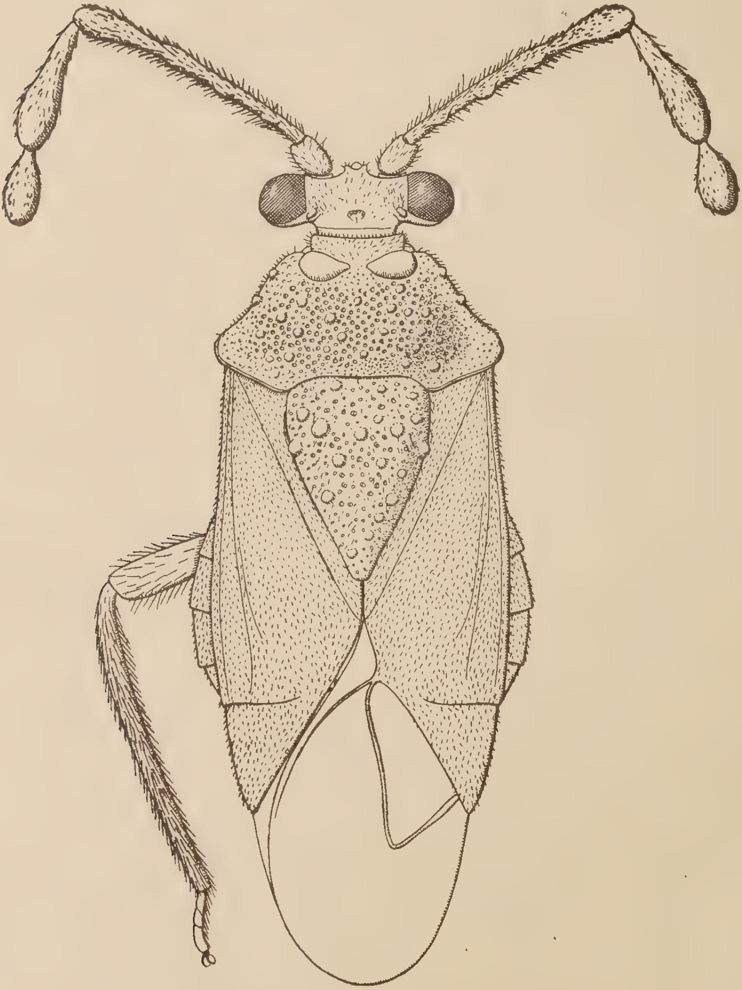

Fig. 8. *Sahlbergella singularis*, Haglund, ♂. Outline to show structure and pubescence; only one hind leg shown to indicate absence of nodular swellings on tibia.

18. Posterior lateral margins of pronotum on each side of base of scutellum dilated and broadly convexly rounded, puncturation of pronotum deep and more or less regular, the surface without small tubercular swellings ; apex of second and the third and fourth antennal segments only slightly thickened.........
Bryocoropsis, Schum. 1917. Type *B. laticollis*, Schum. 1917

Posterior lateral margins of pronotum on each side of base of scutellum not dilated, straight or slightly concave ; puncturation less deep, rugosely confused, surface with small irregularly placed tubercular swellings ; apex of second and the third and fourth antennal segments strongly swollen or clubbed 19

19. Hind tibiae distinctly nodulosely swollen ; eyes small, only one-quarter width of vertex ; acetebula of anterior legs large, visible from above on each side of anterior collar (fig. 7)..*Distantiella*, **gen. nov.**
Type *Sahlbergella theobroma*, Dist. 1909

Hind tibiae simple, not nodulosely swollen ; eyes large, about one-half width of vertex seen from above ; acetebula of front legs small, not visible from above (fig. 8)...*Sahlbergella*, Hagl. 1895
Type *S. singularis*, Hagl. 1895 (=*Deimatostages*, Kuhlg. 1906)

20. Rostrum extending to hind coxae ; pronotum postero-laterally angular ; surface of pronotum densely finely punctate giving a matt surface ; cuneus at base nearly as broad as long ; corium finely shagreened.........*Boxia*, China 1943
Type *B. khayae*, China

Rostrum extending not or little beyond the anterior coxae ; pronotum postero-laterally broadly rounded not angular ; surface of pronotum deeply but not densely punctate giving a shining surface between the punctures ; cuneus longer than wide at base ; corium smooth and shining.............................
Odoniella, Hagl. 1895. Type *O. reuteri*, Hagl. 1895

Pantilioforma, Schumacher.

Schumacher 1917, S. B. Ges. naturf. Fr. Berlin, **1917,** p. 447.

Type : *P. impressopunctata*, Schum. 1917.

There is in the British Museum collection a specimen from Sierra Leone collected by E. Hargreaves which I have identified as *Pantilioforma impressopunctata*, Schum. (fig. 1). If this identification is correct, and short of seeing the type specimen I believe it is, then I consider that *Lycidocoris thoracicus*, Dist., can best be placed in *Pantilioforma*, although it differs in some structural characteristics from Schumacher's poor description. *Lycidocoris modestus*, Dist., differs from both *P. thoracicus*, Dist., and *P. impressopunctata*, Schum., in the elongate instead of equilateral scutellum. All three species, however, agree in the structure of the head, which is much less transverse than in *Lycidocoris*, with the eyes less prominent and extending only half their diameter beyond the anterior lateral angles of the pronotum. The frons too is much more swollen and prominent between the antennae than in *Lycidocoris* and distinctly delimited from vertex by a sinuate transverse furrow not found in *Lycidocoris*. The first antennal segments are much shorter and thicker than they are in *Lycidocoris*. In fact in the structure of the head alone these three species can be regarded as belonging to a single genus distinct from *Lycidocoris*. For the time being, therefore, in spite of differences in the shape of pronotum and scutellum, I propose to regard these three species as congeneric and to place *L. thoracicus* and *L. modestus* in the genus *Pantilioforma*, Schum.

Key to Species of Pantilioforma, *Schum.*

1. Scutellum forming an equilateral triangle..2
Scutellum much longer than wide at base......*P. thoracicus,* Dist. Belgian Congo
2. Pronotum anteriorly only one-third as wide as posteriorly between humeral angles..*P. modestus,* Dist. Belgian Congo
Pronotum anteriorly about one-half as wide as posteriorly between humeral angles (fig. 1) *P. impressopunctata,* Schum. Spanish Guinea and Sierra Leone

Mr. H. E. Box has collected *P. modestus,* Dist., on *Mitragyna stipulosa* at Tafo in the Gold Coast (December, 1942).

Chamus, Distant.

Distant 1904, Ann. Mag. nat. Hist., (7) **13,** p. 197.

Type: *C. wealei,* Dist. 1904.

Chamus boxi, sp. nov. (fig. 9).

Colour ♂ and ♀.—Yellowish brown, darker brown on head and anteriorly on sides of pronotum; first antennal segment fulvous brown, apex of second, whole of the third and fourth segments reddish fulvous; hairs on first segment, black; outer half of cuneus pale yellow, translucent; inner margin of cuneus narrowly and membranal vein bright red; membrane dark brown with two pallid areas one on each side extending from half way up inner side of cuneus to mid-way between apex of cuneus and apex of membrane. Legs yellow, the extreme apices of tarsi and tarsal claws red. Pubescence golden yellow.

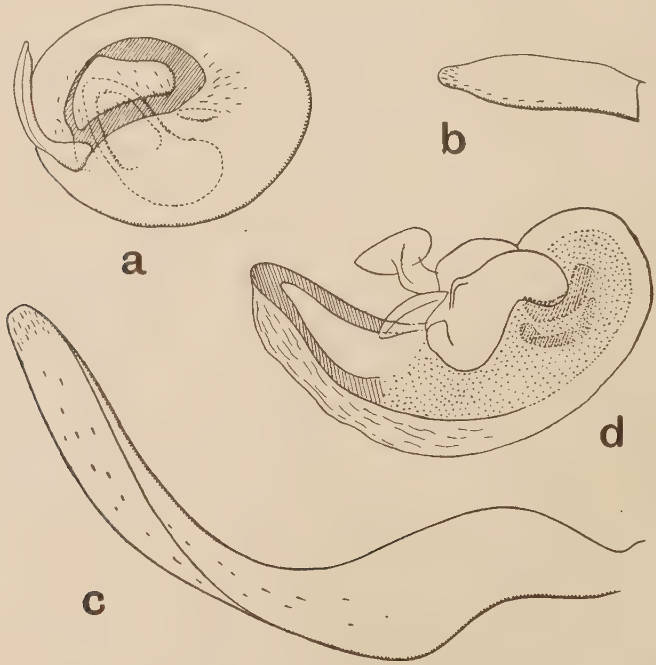

Fig. 9. *Chamus boxi,* sp. nov.: *a,* terminal view of male pygophor and genitalia, the aedeagus shown in dotted outline; *b,* right paramere (dissected and mounted); *c,* left paramere (dissected and mounted); *d,* aedeagus seen from side (dissected and mounted). Different magnifications.

Structure ♂.—Head with long brown bristly hairs, those arising on disc of vertex arranged in two groups one on each side and directed backwards ; head across eyes about one-half wider than long in middle including neck but excluding anterior spines ; eyes small circular ; anterior spines all directed anteriorly in same plane, rather short, the lateral pair about as long as an eye slightly curved outwards (sideways) towards the tip, the median spine straight and distinctly shorter than lateral pair (3 : 5) ; rostrum extending to middle of mesosternum, relative lengths of segments 7 : 5 : 5 : 12. First antennal segment thickened, densely covered with short, black, erect, pointed scales which are about half the width of the segment in length ; remaining segments with sparse pubescence difficult to see and some short erect dark hairs on second and third segments ; relative lengths of segments, 20 : 42 : 26 : 17. Pronotum distinctly wider across humeral angles than long in middle (39 : 28) and more than three times as wide posteriorly as across anterior collar (39 : 12), surface densely granulosely tuberculate each small tubercle giving rise to a posteriorly directed hair, some hairs short and depressed others long and sub-erect. Scutellum equilateral with a semicircular depression at base, remainder concave, transversely wrinkled and with scattered setigerous granules the hairs or setae sub-erect longer than those of pronotum. Hemielytra with scattered setigerous granules, the hairs of varying length from short depressed to long sub-erect, so that surface is densely clothed with hairs ; embolium not transparent although slightly translucent. Legs covered with long fine pubescence, some hairs depressed others erect, those of femora restricted more to the upper surface towards apex. Anterior tibia with a short spur at apex which forms one end of an apical comb of spines (this is a generic character missed by Poppius). Venter pubescent, genitalia figured (fig. 9).

Structure ♀.—Same as male but larger ; relative lengths of antennal segments 21 : 45 : 26 : 18.

Total length : ♂ 5·2 mm., ♀ 6·2 mm. ; width across humeral angles ♂ 1·5 mm., ♀ 1·8 mm.

Habitat : WEST AFRICA, Gold Coast, Bosuso, 3 ♂♂ including type and 2 ♀♀ on *Combretum racemosum*, 30.vi.1943 (*H. E. Box*).

Allied to the W. African *C. mefisto*, Reut. & Popp., but smaller and differently coloured. I am unable to appreciate the difference between *Chamus*, Dist., and *Chamopsis*, Reuter & Popp. The characters given in my generic key are those propounded by Reuter and Poppius but these appear to apply to species of both genera. All species of *Chamus* are more or less "gekornelten," the pubescence of the antennae and legs is variable and the transparence of the embolium is not particularly marked in the species of *Chamus* which I have before me.

Prodromus, Distant.

Distant 1904, Fauna Brit. Ind., Rhyn., **2,** p. 436.

Type : *P. subflavus*, Distant 1904.

Only one species of this genus has so far been recorded from Africa, *Prodromus aethiopicus*, Poppius, found in the leaf sheaths of *Papyrus* spp. in B.E. Africa and Kilimandjaro ; the remaining four species of the genus all occur in the Oriental Region. Mr. Box has now discovered a second African species which is described here.

Prodromus thaliae, sp. nov. (figs. 2 and 10).

Colour ♂ and ♀.—Translucent greenish white (probably pale green in life), tip of rostrum and eyes black, last three antennal segments dark brown, apices of tarsi and tarsal claws dark brown. First antennal segment whitish at base lightly infuscate on apical half. Membranal vein pale green.

Structure ♂.—Head smooth and shining above, the frons with an erect pale pubescence, vertex between eyes concave, that is sunk below level of eyes as in the genotype, less than twice as wide as one eye (23 : 14), not or feebly prominent between the antennae, the eyes sub-stylate not produced posteriorly so that they do not reach the anterior margin of the pronotum ; rostrum short extending only slightly beyond anterior coxae, relative lengths of segments 14 : 10 : 7 : 6 ; antennae long and slender, longer than body, with basal segment thickened on apical two-thirds but slender on basal third, second and third segments slightly thickened but linear, the second widening slightly towards apex, fourth segment filiform, all segments with short pale pubescence ; relative lengths of segments 30 : 65 : 80 : 105. Pronotum with pale pubescence, wider across humeral angles than long in middle (68 : 50) more than twice as wide at base as anteriorly (68 : 30) ; anterior collar and calli feebly elevated and obscurely delimited, the former long (that is, deep), obscurely confusedly punctate, the impression between the latter very shallow ; posterior lobe strongly convex, densely regularly punctate, posterior margin broadly emarginate ;

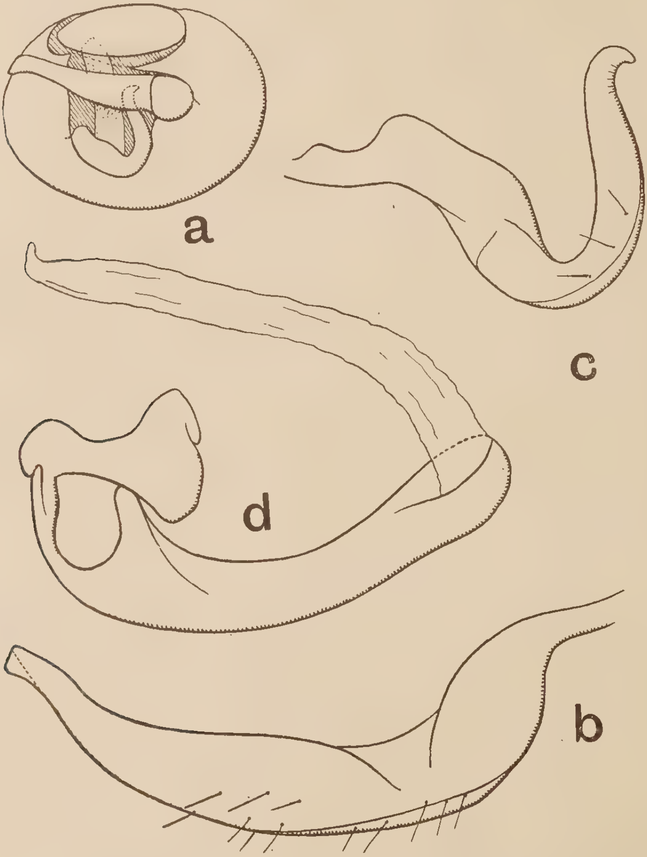

Fig. 10. *Prodromus thaliae*, sp. nov. : *a*, terminal view of male pygophor and genitalia (aedeagus shown dotted) ; *b*, right paramere ; *c*, left paramere ; *d*, aedeagus seen from side ; *b*, *c* and *d* all drawn from dissected and mounted parts. (Different magnifications.)

scutellum more or less equilateral, surface slightly concave, smooth shining. Hemielytra with fairly short, erect, pale pubescence, widely but regularly spaced, the two costal margins convex, so that widest part of two hemielytra, together, is midway between apex of clavus and basal angle of membrane ; surface of clavus and corium sparsely, irregularly faintly punctate. Legs with a pale pubescence and a few longer pale hairs on femora. Genitalia figured (fig. 10).

Total length : 4 mm. ; width across humeral angles 1 mm.

Habitat : West Africa, Gold Coast, Tafo 1 ♂ (type) and 3 ♀♀ on *Thalia geniculata*, 6.xii.1942 (*H. E. Box*).

Closely allied to the Ceylonese *Prodromus cuneatus*, Distant, but slightly smaller, the posterior lobe of pronotum more convex and rostrum shorter not extending to middle of mesosternum.

Stenopterocoris, gen. nov.

A series of specimens taken in Sierra Leone on oil palm in 1925 and on ground nut in 1929 by Mr. E. Hargreaves have been wrongly identified and placed in the British Museum collection as *Prodromus aethiopicus*, Popp. I propose herewith to establish a new genus and species for these specimens which in many respects disagree with Poppius' description.

Allied to *Prodromus*, Distant, but differing in the following characters :—Small narrow elongate species with parallel sided hemielytra. Head not narrowed behind eyes to form a neck, the eyes contiguous with the anterior lateral angles of pronotum and extending posteriorly beyond anterior margin of pronotum ; eyes narrow not sub-stylate as in *Prodromus*, vertex broad and convex ; antennae relatively short and slender. A deep impression on each side of anterior lobe of pronotum behind eyes and a small deep impression in middle between calli. Membranal cell narrow, the vein describing a regular arc without any distinct angulation and meeting cuneus nearly at its apex (fig. 3).

Genotype : *Stenopterocoris laticeps*, sp. nov.

Stenopterocoris laticeps, sp. nov. (figs. 3 and 11).

Colour ♂.—Bright yellow on head shading to deep orange (in mature specimens) on clypeus, posterior half of pronotum and on hemielytra ; eyes black ; antennae with basal segment bright yellow and remaining segments sordid yellow shading to pale fuscous towards the apex ; tip of rostrum black. Apex of scutellum and cuneus pale orange ; pleura and sterna pale yellow ; hemielytra orange yellow to deep orange in mature specimens, membranal vein yellow ; legs pale yellow with apices of middle and hind tibiae and tarsi infuscate. Abdomen orange yellow, paler towards apex.

Structure ♂.—Head smooth and shining with some erect pale hairs, densest below in front of eyes ; vertex between eyes convex, not sunk below level of eye as in *Prodromus*, nearly three times as wide as one eye (35 : 12), roundly prominent between antennae, the eyes not substylate as in *Prodromus* but elongate and produced posteriorly well beyond anterior margin of pronotum ; rostrum extending to intermediate coxae, relative lengths of segments 15 : 20 : 16 : 15 ; antennae with basal segment distinctly thickened, shorter than head in middle, second segment slightly thickened and slightly curved, third and fourth slender ; all segments distinctly pilose, the first with a few long erect bristles ; relative lengths of segments 18 : 42 : 47 : 45. Pronotum with pale pubescence ; distinctly wider across humeral angles than long in middle (66 : 57), about half as wide anteriorly as wide at base (36 : 66), with a broad median impression (deep in middle) anteriorly immediately behind anterior margin, extending nearly to lateral margins, anterior collar indistinctly delimited, calli convex but indistinctly delimited ; anterior region of pronotum smooth unpunctate, posterior region strongly punctate ; posterior margin emarginate. Scutellum smooth and shining, equilateral with a broad shallow impression in middle of base. Hemielytra with pale short depressed pubescence the two costal margins more or less parallel ; no longitudinal vein extending from basal angle of membranal cell. Legs with pale pubescence and some long pale bristles especially towards apices of hind femora. Wing cell without hamus. Venter with erect pale pubescence and some longer hairs. Genitalia figured (fig. 11).

Total length : 4·0 mm. ; width across humeral angles 1·0 mm.

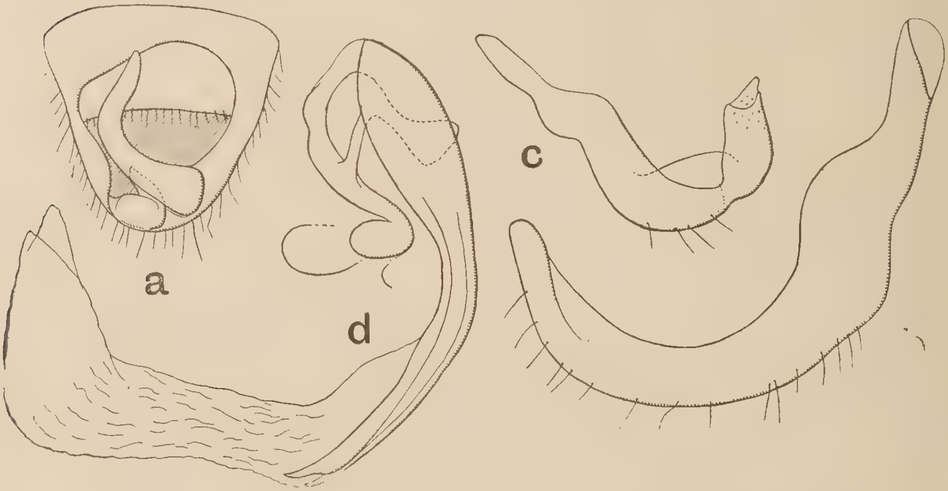

Fig. 11. *Stenopterocoris laticeps*, gen. et sp. nov. : *a*, terminal view of male pygophor and genitalia (aedeagus not shown) ; *b*, right paramere ; *c*, left paramere ; *d*, aedeagus seen from side ; *b*, *c*, and *d*, all drawn from dissected and mounted parts. (Magnifications not necessarily the same in each case.)

Habitat : West Africa, Sierra Leone ; Njala, 7 specimens 23.i.1925 and 6 specimens 19.vi.1925, on Nigerian oil palm ; Blama, 1 specimen 11.i.1925 ; Newton, 4 specimens (including type ♂) 7.viii.1929 on ground nut (Coll. *E. Hargreaves*).

Poppiusia, gen. nov.

Closely allied to the Oriental *Pachypeltis*, Signoret 1858, Ann. Soc. ent. France, (3) **8,** p. 501 (synonym *Disphinctus*, Stål 1870, Ofvers. VetenskAkad. Förh. Stockholm, **27,** p. 668) (fig. 5) but differing in the much broader embolium which is about half the width of the clavus at base ; in the much broader cuneus, only one-half longer than wide at base and in the non-reflexed margins of humeral angles of pronotum. The row of punctures down embolial and claval sutures very distinct.

Genotype : *Poppiusia combretorum*, sp. nov.

The genus *Pachypeltis* contains about 21 species widely distributed over the Oriental Region from Formosa and South China through the Philippines and Malay Archipelago to India and Ceylon. In Australia it is replaced by *Pachypeltopsis*, Poppius 1912, and in South America by the allied genus *Monalonion*, H.S. 1850. It is not surprising therefore to find still another related genus in Africa which we are glad to dedicate to the celebrated Finnish Hemipterist, the late Dr. B. Poppius, in recognition of his monumental work on the African Miridae.

Poppiusia combretorum, sp. nov. (figs. 4 and 12).

Colour ♂.—Shining orange yellow sometimes fulvous, antennae (except extreme base of first segment) and eyes black ; lateral margins of head along inside of eyes and posterior lateral areas behind eyes, infuscate ; hemielytra dark brown, embolium (except the dark brown apex) translucent pale yellow, inner apical angle of corium and basal lateral margin of cuneus also obscurely yellowish ; membrane brownish black, its veins concolorous ; hind wings fuscous. An obscure fuscous suffusion on middle of hind femur ; hind tibia (except extreme base) and all the tarsi dark brown to black. Apex of venter and genital segments infuscate.

Colour ♀.—Similar to ♂ but cuneus (except dark brown apex), inner apical margin of corium and angle of membranal cell vein, bright orange yellow. Middle of membrane around angular cell vein, whitish hyaline. Hind femur without the fuscous suffusion in middle. Venter sanguineous, ovipositor dark brown.

Structure ♂.—Head smooth and shining with erect long dark hairs ; about twice as wide across eyes as long in middle including neck (29 : 15) ; vertex between eyes two and a half times width of one eye (16 : 6·5) ; neck same width as vertex between eyes ; rostrum short not reaching apices of front coxae, relative lengths of segments, 7 : 6 : 5 : 10. Antennae with dark pubescence and some longer erect hairs especially

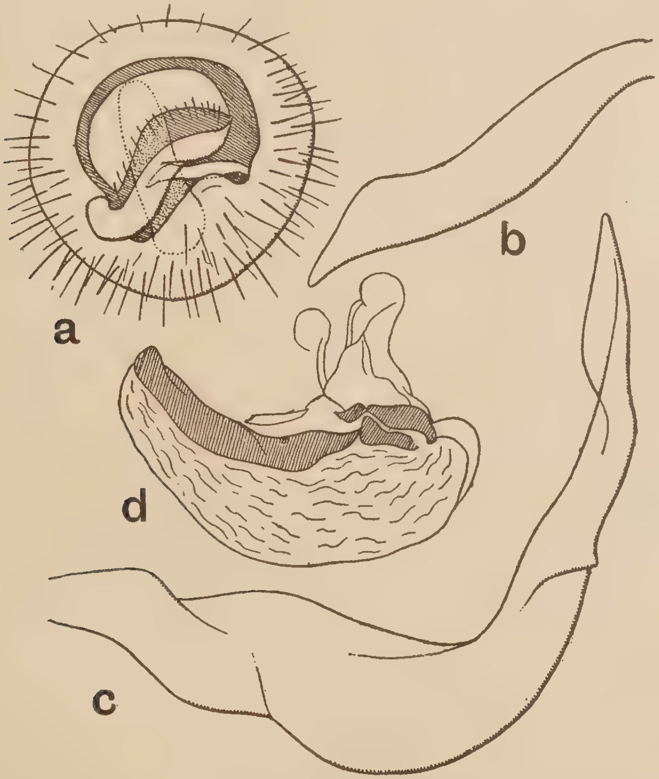

Fig. 12. *Poppiusia combretorum*, gen. et sp. nov. : *a*, terminal view of male pygophor and genitalia (aedeagus shown in dotted outline) ; *b*, right paramere ; *c*, left paramere ; *d*, aedeagus seen from side ; *b*, *c*, and *d*, all drawn from dissected and mounted parts. (Different magnifications.)

on first segment; the first segment slightly thickened the remainder linear; relative length of segments 22 : 65 : 40 : 20. Pronotum smooth and shining with long erect dark pubescence which is somewhat depressed along basal margin; distinctly wider across humeral angles than long in middle (48 : 35) and about two and a half times wider across humeral angles than at anterior collar (48 : 18); the latter about half as long in middle as wide (9 : 18); calli convex distinctly delimited by a deep furrow from anterior collar and posterior lobe of pronotum, the latter moderately convex, the humeral angles rounded, not at all reflexed, delimited from main lobe by a distinct depression; posterior margin only very slightly emarginate. Scutellum more or less equilateral, smooth and shining with an erect dark pubescence, with a semicircular depression at extreme base and some transverse wrinkling towards apex. Hemielytra intensely shining covered with a fine erect dark brown pubescence; extending by more than half the length of the membrane beyond apex of abdomen; embolium broad about half width of clavus, width of cuneus at base about two-thirds its length; the row of punctures down embolial and claval sutures fine but distinct. Legs simple with fine erect, moderately long brown pubescence. Genitalia figured (fig. 12).

Structure ♀.—Similar to ♂ but with larger relative measurements. Relative lengths of antennal segments 27 : 75 : 45 : 25.

Total length: ♂ 8·5, ♀ 10 mm., width across humeral angles ♂ 2 mm., ♀ 2·3.

Habitat: West Africa, Gold Coast, Tafo 2 ♂♂ (including type) and 3 ♀♀ on *Combretum* sp., July 1943 (*H. E. Box*).

Idioaspis, gen. nov.

Shining glabrous except for short pubescence on elytra, antennae and legs. Head smooth shining transverse, more than twice as wide as long, eyes laterally prominent, disc of vertex convex in middle so that it is on level with upper surface of eyes as in *Odoniella*: base of clypeus visible from above; two very minute tubercles anteriorly between antennae above base of clypeus; vertex with a pair of small tubercles in middle on level with the eyes and separated by a shallow furrow; antennae thick and robust with basal segment sub-globular, second longest, thickened

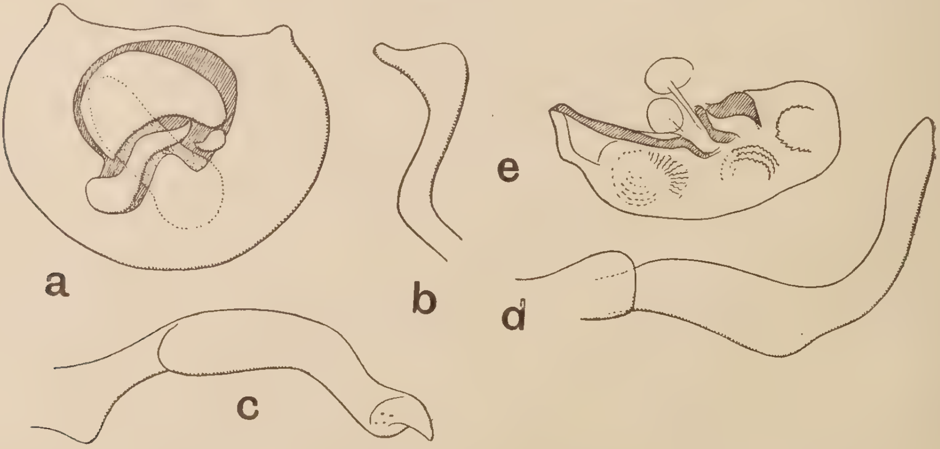

Fig. 13. *Idioaspis macarangae*, gen. et sp. nov.: *a*, terminal view of male genitalia and pygophor (aedeagus shown dotted); *b*, right paramere (dissected and mounted); *c* and *d*, left paramere from different viewpoints (dissected and mounted); *e*, aedeagus seen from side (dissected and mounted). (Magnifications not all the same.)

towards apex, third and fourth thickened, fusiform. Pronotum more than twice as wide as long ; anterior collar with four equally spaced erect tubercular processes, the lateral pair short and conical, the middle pair much longer, about twice as long as wide and nipple shaped ; calli intensely shining separated by a median longitudinal ridge ; disc of pronotum with two rows of equally spaced tubercular conical processes ; the anterior row of four placed immediately behind the calli consists of two relatively short lateral processes and two much broader and longer median processes, the posterior row of six consists of two lateral and two median placed behind those of the anterior row and an additional pair placed one each between the median processes and the lateral ones, the median pair longest ; posterior lateral angles of pronotum strongly dilated and reflexed, the margin deeply regularly serrate ; surface of pronotum between the processes more or less reticulately wrinkled, the propleural wrinkling becoming almost a coarse shallow puncturation. Scutellum strongly swollen, split up into six lobes, a large basal lobe with a longitudinal median furrow, three apical lobes, the median larger than the two lateral but all pointed at apex, and two small circular lateral lobes ; the whole surface reticulately wrinkled. Hemielytra smooth and shining with cuneus translucent about twice as long as broad at base ; membrane with cell vein rectangular and some confused longitudinal wrinkles and sub-venation beyond the cell. Legs with minute setigerous tubercles. Venter with connexivum dilated and reflexed, sub-hyaline, the posterior angle of each segment prominent.

Genotype : *Idioaspis macarangae*, sp. nov.

Allied to *Sahlbergella* but distinguished by the processes on anterior pronotal collar and by the remarkable scutellum.

Idioaspis macarangae, sp. nov. (figs. 6 and 13).

Colour ♂ and ♀.—Varying from pale brownish white in teneral specimens to dark brown in mature forms. Head pale brown with tip of rostrum and eyes dark brown to black ; first antennal segment dark brown, second segment brownish yellow shading to dark brown towards apex, third segment dark brown with apex broadly whitish, fourth segment dark brown with extreme apex whitish ; pubescence dark brown. Pronotum whitish with a dark brown median longitudinal strip widening posteriorly, its lateral margins indistinct, sometimes pronotum entirely dark brown except for calli which are yellowish brown. Propleura whitish ; scutellum brownish white with disc of basal lobe and apices of apical lateral lobes, dark brown ; sometimes scutellum entirely dark brown. Hemielytra brownish yellow with some dark brown mottling made up by the grouping or scattering of small brown spots ; cuneus pale brownish yellow, membrane dark brown to black with two small pale triangular areas (appearing as four when hemielytra closed) one at intersection of membranal vein with inner margin of cuneus the other a little below this on costal margin of membrane. Legs pallid with dark brown annulation, two or three broad rings on femora and four or five narrow rings on tibiae ; two basal tarsal segments and apex of apical tarsal segment dark brown. Abdomen yellowish brown with indistinct darker brown transverse bands on posterior half of connexival segments.

Structure ♂.—Head about two and a half times wider across eyes than long in middle (27 : 10) ; vertex nearly seven times as wide as diameter of one eye (27 : 4) ; rostrum extending to bases of middle coxae ; relative lengths of antennal segments 7 : 44 : 30 : 20 ; antennal pubescence very short and stiff, moderately dense, fourth segment about one-fourth as wide at widest part as long, the third segment slightly thinner than this at its widest point. Pronotum twice as wide across humeral angles as long in middle (60 : 30) and not quite four times width at anterior collar (including lateral tubercles) (60 : 17). Scutellum extending backwards over apex of clavus to inner basal angle of membrane. Clavus narrowed in middle ; embolium narrow at base suddenly widened ; membrane relatively narrow and elongate, extending by half its length beyond apex of cuneus ; pubescence of hemielytra very short sub-erect, slightly longer on cuneus. Pubescence on legs relatively short, longest on tibiae. Genitalia figured (fig. 13).

Structure ♀.—Similar to male but relative measurements different.

Total length : ♂ 4·7 mm., ♀ 5 mm. ; width across expanded humeral angles ♂ 2·5 mm., ♀ 3 mm.

Habitat : West Africa, Gold Coast, Bosuso, 2 ♂♂ (including type) and 3 ♀♀ on *Macaranga horaefolia*, 30.vi.1943 (*H. E. Box*).

This very remarkable Mirid undoubtedly belongs to the *Sahlbergella-Bryocoropsis* group of species which Dr. Schouteden (Rev. Zool. Bot. afr., **26**, p. 473, 1935) has suggested should be considered as belonging to one genus. He states that if *Bryocoropsis* is to be distinguished generically from *Sahlbergella* then logically *S. singularis*, Hagl., and *S. theobroma*, Dist., must also be separated. There is a considerable amount of truth in this, and I am inclined to agree with him. I have considered regarding *Idioaspis*, *Bryocoropsis* and *Sahlbergella* as one genus but after some deliberation have decided to regard them as distinct genera separated as in the foregoing key. It remains, therefore, to propose a new genus for *Sahlbergella theobroma*, Dist., and to place Schouteden's (1935 *loc. cit.*) four new species of *Sahlbergella* in their correct genera.

Distantiella, gen. nov.*

Closely allied to *Sahlbergella*, Hagl. 1895, type *S. singularis*, Hagl. 1895 (fig. 8) but differing in the following characters.

Eyes much smaller only about one-quarter instead of one-half width of vertex.

Pronotum much less narrowed anteriorly ; acetabula of anterior legs very prominent laterally and broadly visible from above so that anterior width of front of pronotum is more than half its width across humeral angles, whereas in *Sahlbergella* it is barely one-third and the acetebula of the front legs are not visible from above. Middle and hind tibiae nodulosely swollen instead of simple as in *Sahlbergella*.

Genotype : *Sahlbergella theobroma*, Dist. 1909 (fig. 7).

Schouteden's (1935 *loc. cit.*) four new species of *Sahlbergella* may be placed as follows :—

Sahlbergella collarti, Schout.

As pointed out by Schouteden, this species is closely allied to *S. theobroma*, Dist., and consequently must be referred to the new genus *Distantiella*. It differs from *S. theobroma* in the larger size, longer antennae, longer scutellum with the tip of its vesicle curved downwards and in the surface of pronotum and scutellum more strongly sculptured and punctate.

Sahlbergella maynéi, Schout.

This undoubtedly belongs to the true *Sahlbergella*, in spite of its rather smaller and less posteriorly produced vesicle of scutellum and the slightly smaller less pediculate eyes. There is a series of this species in the British Museum from Mlanje, Nyasaland, collected in 1938 by Mr. C. Smee.

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* Dedicated to W. L. Distant, my predecessor at the Museum and the author of the typical species, in recognition of his extensive work on the Hemiptera.

Sahlbergella ghesquièrei, Schout.

As pointed out by Schouteden, this species is closely allied to *S. singularis*, Hagl., differing principally in the short vesicle of the scutellum, and therefore belongs to the genus *Sahlbergella.* There is a single specimen in the British Museum collected by Monsieur C. Primot at Libreville, Gabon, in 1936.

Sahlbergella soror, Schout.

S. reuteri, Schout. 1935 (in litt.) loc. cit. p. 474.

Judging by the description alone, I am inclined to place this species in the genus *Bryocoropsis*, Schumacher 1917. Some of its characters, however, appear to be intermediate between *Bryocoropsis* and *Sahlbergella.*

Subfamily Macrolophinae.

Division Macrolopharia.

Lasiolabops obscurus, Popp.

Poppius 1914, Acta Soc. Sci. fenn., **44,** no. 3, p. 27.

Amongst Mr. Box's Gold Coast material are four specimens from Tafo collected on *Ficus asperifolia* on 21.xii.1942. These specimens agree very well with Poppius' description, which was based on a single female, and undoubtedly belong to his genus *Lasiolabops.* They differ, however, in one important character. Poppius says " Die Hinterflügelzelle ohne Hamus," but in Box's specimens a very distinct hamus is present. It seems likely that as Poppius placed this aberrant genus in the Macrolopharia in which he states " Die Hinterflügelzelle immer ohne Hamus," that he assumed the hamus was absent without looking. This species has the general appearance of one of the *Labops* group of genera in the Heterotominae but differs in the structure of the arolia which are fused to the claws for the basal two-thirds of their length instead of being free with the tips converging. The presence of a hamus in the hind wing cell might have no significance since in the Systellonotaria this can be present or absent. Poppius' single ♀ might possibly have been a pathological specimen.

Division Systellonotaria.

Diocoris collaris, sp. nov. (fig. 14).

Colour, macropterous ♂.—Dull black with base of third antennal segment broadly pale yellow, first antennal segment except base and apex, sordid yellowish brown, and a small obscure spot at apex of intermediate femora sordid yellow. Hemielytron with an equilateral triangular area with its base along middle of costal margin, and its apex just invading the clavus translucent silvery white ; surface of hemielytron dull black with the apical fourth of corium and the cuneus shiny black ; also with two transverse bands across closed hemielytra showing up as a silvery sheen in certain lights, one broad band extending across each clavus above the level of the triangular white marks, the other extending completely across hemielytra from one costal margin to the other just below the triangular white marks. Legs with a reddish shade underlying the black and cuneus also with a reddish tinge in the black.

Structure, macropterous ♂.—Head large and strongly inclined, wider across eyes than long in middle seen from above (39 : 32) and three times as wide as vertex between the very large eyes (39 : 13) ; nearly twice as long as high at base, seen from side (45 : 25) ; rostrum reaching base of middle coxae. Antennae without hairs or bristles. Relative lengths of antennal segments 26 : 70 : 80 : 40, the second segment slightly thicker than first and thickest towards apex ; vertex with a few very short erect bristles. Pronotum with a few scattered short bristles on posterior half rather more than twice as wide across humeral angles as across anterior collar (50 : 23) the latter distinctly flattened and slightly reflexed not lying in same plane as disc of pronotum, as it does in *D. agelastus*, Kirk. Scutellum glabrous, shining, longer than broad, strongly convex with mesonotum uncovered at base by the broadly emarginate posterior margin of pronotum. Hemielytra extending well beyond apex of abdomen, with a rather sparse depressed pubescence especially apically, and a number of scattered short erect black bristles ; cuneal fracture very distinct, cuneus more than twice as long as broad at base ; its apex rounded not pointed ; membranal vein rectangular but the angle rounded, the vein separating the small cell straight. Hind femora lightly thickened in middle and tapering to apex ; hind tibiae slightly thickened on the basal third thence tapering to apex. Femora with short black bristles forming a distinct and regular row on dorsal surface of hind femora ; tibiae with rows of short sub-erect black bristles visible only with higher magnifications ; tarsi long and slender. Venter shining with a depressed sparse pubescence and the apex of the pygophor below genitalia, ending in a distinct short spine-like process ; genitalia figured (fig. 14).

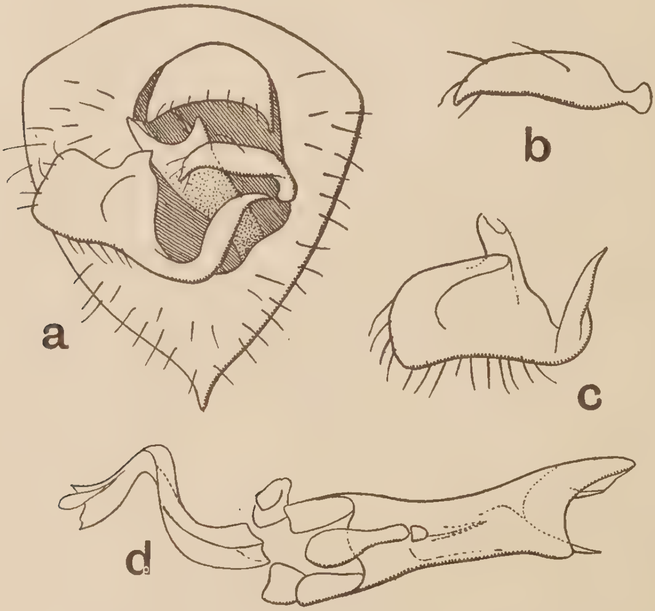

Fig. 14. *Diocoris collaris*, sp. nov : *a*, terminal view of male pygophor and genitalia ; *b*, right paramere ; *c*, left paramere ; *d*, aedeagus seen from the ventral side (preparation was broken into three parts which may not be correctly joined in drawing) ; *b*, *c* and *d*, all drawn from dissected and mounted parts. (Magnifications different.)

Habitat : West Africa, Gold Coast, Nkawkaw, 4 macropterous ♂♂ (including type) collected at light 3.vi.1943 (*H. E. Box*).

Addendum.

A study of the genitalia of these few species of Miridae shows that the structure of the aedeagus is of value for categories higher than genera. Whereas *Chamus*, *Poppiusia* and *Idioaspis* obviously belong to the same group of genera, *Prodromus* and *Stenopterocoris* are distinct from this group and are not themselves closely allied.

Diocoris, belonging to a distinct subfamily, has an entirely different type of aedeagus. It is doubtful whether this structure could be used for categories as high as subfamilies. The parameres are of course merely of specific value within the genera. In figuring the genitalia I have given first a terminal (end on) view of the male pygophor undissected with the genitalia *in situ* and then figures of the dissected-out parts, parameres and aedeagus mounted in clove oil and drawn under the monocular microscope in transmitted light. Owing to the curved and twisted nature of these parts no two views look alike, and I have therefore drawn the view presented by the dissection when at rest on the microscope slide without support.

A NEW SUB-SPECIES OF *GLOSSINA* FROM UGANDA (DIPTERA).

By F. I. van Emden,

Imperial Institute of Entomology.

In November 1939, Mr. G. H. E. Hopkins, Senior Medical Entomologist in Kampala, reported to me that he, together with Mr. T. W. Chorley, had discovered *Glossina nigrofusca*, Newst., in Uganda. As *G. nigrofusca* is a rare West African species, this find was rather unexpected, and he asked me to check the identification. The exterior characters of the two specimens sent in were entirely those of *G. fusca*, but after dissecting the male genitalia of a West African *G. nigrofusca*, I could not but agree that the Uganda specimens were quite as like the latter species.

It seemed at first that the new form could with equal justification be considered a race of *fusca* with deviating genitalia or a race of *nigrofusca* with a different third antennal joint. The frequency with which races are characterised only by differences in the male terminalia or are at least more clearly defined in the latter organs than in other parts of the body, would *prima facie* have made the first possibility more probable. However, the following facts make it quite clear that the new race belongs to *nigrofusca*, and not to *fusca* : (1) the characters of the male terminalia (fig. 3) deviating from those of *fusca* (fig. 4) and agreeing with those of *nigrofusca*, are of a highly complex nature, whilst the length of the ciliation of the third antennal joint (figs. 1 and 2) is a relatively simple character, which is more likely to vary as a first step in the separation of two geographical forms ; (2) a *nigrofusca* form with somewhat shorter antennal fringe has already been discovered in the Gold Coast (Hegh, 1929, Les Tsé-tsés, p. 359) ; (3) it would be highly improbable that the male terminalia and the signum in the female uterus (which do not of course enter into contact during copulation) should both have characters identical in *nigrofusca* and a new race of a different species.*

The new form is therefore being described as :—

Glossina nigrofusca hopkinsi, subsp. n. Head as in *fusca* and *nigrofusca*, cilia of the fringe of the third antennal joint about one-eighth the length of the largest diameter of the joint (fig. 1). The peristomal setae and the row of setae running from the lower part of the eyes along the front margin of the occipital dilatation as a rule largely black. Mesonotum somewhat more strongly convex and more steeply sloping to notopleurae than in *fusca*, therefore appearing broader and stouter, setae as in *fusca* and *nigrofusca* ; pleurae largely pale brown, the suffusions not differing from the type and *fusca*, the infra-alar bulla testaceous. Setulose hairs of the anterior surface of the front coxae black, but those near the margins golden-yellow. Front femora with a slight brownish posterior suffusion, the posterior femora with a somewhat more conspicuous anterior suffusion, fore tibiae wholly pale, mid tibiae with an indistinct brownish suffusion in middle, hind tibiae with a broad brown suffusion in middle, the apex pale, at most with a very small and slight vestige of a suffusion on anterior surface ; the apical two joints of the hind tarsi fuscous. Tergites brown, the last ones more darkly so, the hind margins often narrowly and suffusedly paler. ♂ genitalia : exactly as in *nigrofusca*, *i.e.* the vesica with a striking dark brown elongate concave sclerite which extends far beyond the apex of the harpes, the latter small, spiniform V-shaped and directed towards the body ; the parameres (inferior claspers, gonopods) angularly pointed towards basal part of penis (fig. 3). ♀ genitalia : signum as in *nigrofusca*, *i.e.* membranous with a pair of divergent sclerotised bands (fig. 5).

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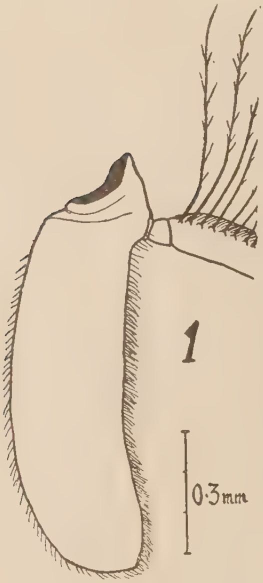
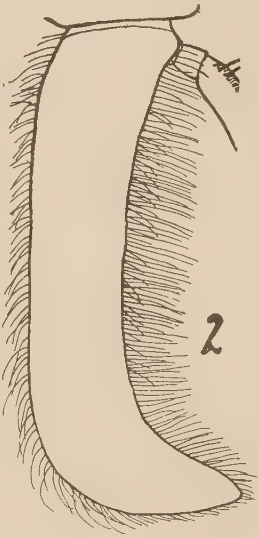
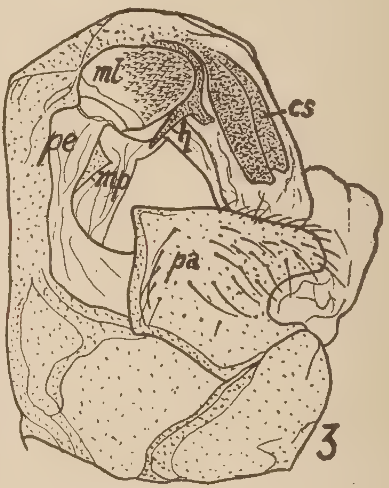
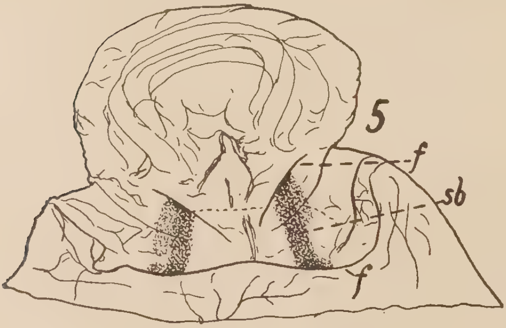
* The latter argument has resulted from a discussion of the question with Dr. A. S. Corbet, whom I wish to thank for communicating his experience of this point in Lepidoptera.

W. Uganda : Muntande, Bwamba, Toro, 15–31. iii.41 ♂ type, 5 ♂ 3 ♀ paratypes, ii.41 2 ♂ paratypes, iv.41 8 ♂ paratypes, v.41 2 ♂ paratypes, viii.41 1 ♂ paratype, x.41 5 ♂ paratypes, xii.41 7 ♂ paratypes, ii.42 6 ♂ paratypes, v.42 6 ♂ paratypes (*J. K. Hunter*), 12.ix.35 5 ♂ paratypes, genitalia slides 6, 10, 411, 412, 414 (*H.*









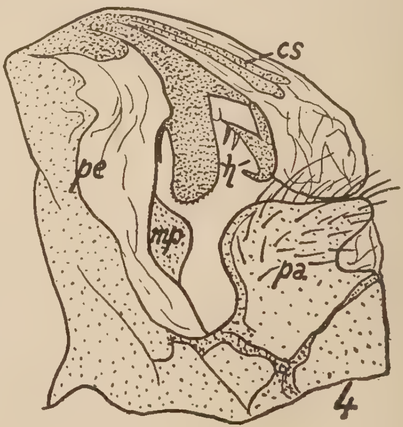


Fig. 1. Third joint of left antenna of *G. nigrofusca hopkinsi*, Emd., from Muntande River.

Fig. 2. Third joint of left antenna of *Glossina nigrofusca nigrofusca*, Newst., from Kumasi-Bekurai, Ashanti.

Fig. 3. Male terminalia of *G. nigrofusca hopkinsi*, Emd., from Muntande River : *cs*, concave sclerite ; *h*, harpes ; *ml*, membranous asperate lobe ; *mp*, median process ; *pa*, paramere ; *pe*, penis.

Fig. 4. Male terminalia of *G. fusca congolensis*, Newst. & Ev., from Muntande River. Lettering as in fig. 3.

Fig. 5. Female signum of *G. nigrofusca hopkinsi*, Emd., from Makoka. The middle part folded up as in natural position, the sclerotised band therefore partly seen by transparence : *f*, fold ; *sb*, sclerotised band.

(Figures drawn with a Leitz microscope, eye-piece 2 and objective 3, and a camera lucida.)

Hargreaves) ; Makusakusa, Bwamba, Toro, v.42 (*J. K. Hunter*) 5 ♂ paratypes ; Makoka, 4.ii.41 (*J. K. Hunter*) 1 ♀ paratype, genitalia 4118 ; Rumandye, Muntande Clearing, 4.ii.41 3 ♂ paratypes, genitalia slides 31, 32, 34, ix.41 10♂ paratypes, xi.41 5 ♂ 1 ♀ paratypes (*J. K. Hunter*) ; Mpulia, Bwamba, Toro, 4.ii.41, 1 ♂ paratype, genitalia slide 36.

Among the considerable series of *G. fusca* in the British Museum, there are only two specimens of this subspecies, both females (whereas this sex is very scarce among the Uganda material) from BELGIAN CONGO : Stanleyville, Ituri Region, 1932, and Km. 396, ii.32 (*J. Schwetz*). Both these females are somewhat atypical in that they have all the peristomal setae and some of the discal hairs of the front coxae golden yellow ; their hind tibiae and signum, however, are as described for *hopkinsi*.

The type and numerous paratypes are in the British Museum (Natural History). Paratypes will also be sent to Mr. Hopkins and, at his request, to the London and Liverpool Schools of Tropical Medicine.

Both the Muntande and Makusakusa are, according to Mr. Hopkins, small rivers in the forest, about half a mile apart. The Rumandye is a third river and apparently near the Muntande. At almost every one of the above localities *G. nigrofusca hopkinsi* was mixed with *G. fusca congolensis* and *fuscipleuris*. According to Mr. J. K. Hunter, his African boy could only capture these flies about sunset (at 6.30 p.m.) and only near the stream. This latter fact may, in Mr. Hopkins' view, " really imply a close connection with forest " instead of water. The scarcity of females may perhaps be explained by the crepuscular habits, if the bulk of the females of *hopkinsi* fly only when it is more or less dark. The females of the other two species are quite common in the material, and therefore appear to fly freely about sunset, like the males of all the species concerned.

Glossina nigrofusca and the new subspecies belong to a group of the genus which has been defined as the *fusca*-group by Newstead (subgen. *Austenina*=*Newsteadina* Tns.) on the basis of the free superior forceps of the male and the usually developed signum and five external genital plates of the female. Townsend (1935, Man. Myiol., **2,** p. 117) has found a character visible without dissection in the relative length of the pteropleural and sternopleural setae, these being of subequal length in the *fusca* group, whilst in *Glossina* s. str. (including *Nemorhina* R.-D.) the pteropleura bears only setulose hairs, which are shorter than the sternopleurals. Some additional characters have come to light during the present studies. These render the *fusca* group a rather well defined aggregate, to which subgeneric status may well be attributed.

1. (2) Hairs in the fringe of the lower calyptra straight or simply and gradually curved, not very dense ; hind margin of lower calyptra strongly diverging at base from scutellum and from longitudinal axis of fly, rather evenly rounded exteriorly, the calyptra therefore reminiscent of that of Phaoniinae. Sides of scutellum largely or only covered with black setules. Pteropleurae only with setulose hairs, which are considerably shorter than the sternopleural setae. ♂ : superior forceps connected by a membrane. ♀ : signum of uterus absent ; 6 or 3–4 external genital plates present.................. subgen. *Glossina*, s. str.

2. (1) The lower row of hairs in the fringe of the lower calyptra longer and wavy in the apical part, hairs therefore looking " untidy," very numerous and dense ; hind margin of lower calyptra for a short distance at base only moderately diverging from scutellum and parallel with longitudinal axis of fly, only slightly rounded in exterior half, the calyptra therefore somewhat reminiscent of that of Muscinae. Lower part of sides of scutellum with rather long soft yellow hairs. Pteropleurae among the setulose hairs with a few strong setae, which equal in length the sternopleural setae. ♂ : superior forceps free. ♀ : signum of uterus almost always present ; five external genital plates (none of them in a medio-dorsal position) .... subgen. *Austenina*

Among the species of *Austenina* with long proboscis and palpi (the latter at least one-sixth longer than the greatest head-width from inner, more median end of base to apex), *nigrofusca* and *fusca* with their subspecies are recognised (in addition to characters of the genitalia) by the following key :—

1. (10) Only the last two joints of the hind tarsi dark, or the pleurae pale brown.
2. (3) Fringe of third antennal joint one-half to three-fourths the width of the joint. Hind tibiae with a broad and dark suffusion on middle and a much less distinct one at apex. Infra-alar bulla dark brown to fuscous... *nigrofusca nigrofusca*, Newst.
3. (2) Fringe of third antennal joint less than one-fourth the width of the joint.
4. (9) Infra-alar bulla testaceous, often with a yellow vertical streak in centre (caused by dried-up tissues).
5. (8) Fringe of third antennal joint about one-eighth the width of the joint. Proboscis and palpi somewhat longer, the latter at least one-fifth longer than head-width.
6. (7) Hind tibiae with a broad and dark suffusion in middle, the apex not or hardly infuscate. Setae and hairs on anterior surface of front coxae all black except those on the margins. Some of the peristomal setae usually black ....*nigrofusca hopkinsi*, **subsp. n.**
7. (6) Hind tibiae without or with a dark suffusion in middle, in the latter case a hardly less distinct one at apex present. At least some of the setae and hairs on the anterior surface of the front coxae golden-yellow in addition to those on the margins. Usually all the peristomal setae golden yellow ....*fusca fusca*, Wlk. and *fusca congolensis*, Newst. & Ev.
8. (5) Fringe of third antennal joint about one-fifth the width of the joint. Proboscis and palpi somewhat shorter, the latter one-sixth longer than head-width...*haningtoni*, Newst. & Ev.
9. (4) Infra-alar bulla dark brown to fuscous, without a pale vertical streak in centre ....*fuscipleuris*, Austen
10. (1) All the joints of the hind tarsi dark. Pleurae and hind coxae fuscous-grey... *severini*, Newst.

DESCRIPTION, BIONOMICS AND CONTROL OF THE GIANT MEALYBUG, *DROSICHA STEBBINGI*, GREEN (HOMOPTERA : COCCIDAE).

By Khan A. Rahman, B.Sc.Agric. (Edin.), Ph.D.(Cantab.) & M. Abdul Latif, B.Sc.Agric.(Pb.).

Entomological Section, Punjab Agricultural College and Research Institute, Lyallpur.

(Plate II.)

The giant mealybug, *Drosicha stebbingi*, Green, which occurs in Northern and Central India, was described for the first time in 1900. Observations on its life-history and control have been made by Stebbing (1899–1903) at Dehra Dun, Lefroy (1908) and Dutt (1925) at Pusa, Richards & Sharma (1934) at Cawnpore, and Misra & Rao (1938) at Benares. Savage (1914) investigated the respiratory system of the female. Hingston (1929) made observations in Central India. Beeson (1941) has briefly recapitulated its life-history and control. Though it has thus been the subject of investigation by a number of workers since 1900, the information so far collected is far from complete. No effective control has yet been devised, for the existing methods of combating it are directed towards preventing the fertilised females from descending the trees and entering the soil to oviposit, and this is *after* the damage has been done. Its habits, which have an important bearing on its control, have not yet been fully studied, and the present investigations were, therefore, undertaken in 1938. The results are presented in this paper.

Distribution and Food-plants.

D. stebbingi was first reported by Stebbing in 1899–1900 from Dehra Dun on sal (*Shorea robusta*) and from Lahore on mango (*Mangifera indica*) ; he also collected it at Bareilly, Darbhanga, and Dalsing Serai (Tirhoot Division) in 1902. Lefroy (1908) found it at Pusa on banyan (*Ficus benghalensis*), "pakur" (*F. infectoria*), "pipal" (*F. religiosa*), "gular" (*F. glomerata*), fig (*F. carica*) and "sissoo" (*Dalbergia sissoo*) and in Dalsing Serai on "jak" (*Artocarpus integrifolia*). Fletcher (1917) found it on guava (*Psidium guava*), peach (*Prunus persica*), plum (*P. communis*), pomegranate (*Punica granatum*), sapota (*Achras sapota*), and mulberry (*Morus alba*), and Dutt (1925) collected it on papaya (*Carica papaya*) at Pusa. Hingston collected it on tamarind (*Tamarindus indica*) in 1929 in Central India. Rahman studied its distribution and food-plants in the N.W.F. Province and the Punjab from 1937 to 1940 and found it widely distributed on "ber" (*Zizyphus jujuba*), "kachnar" (*Bauhinia variegata*), sunflower (*Helianthus annuus*), rose (*Rosa indica*), *Duranta* sp., cherry (*Prunus cerasus*), hollyhock (*Althaea rosea*), *Citrus* sp., "kaner" (*Nerium odorum*), "jaman" (*Eugenia jambolana*), "loquat" (*Eriobotrya japonica*), grape-vine (*Vitis vinifera*), jasmine (*Jasminum sambac*), siris (*Albizzia lebbek*), *Hibiscus* sp., apple (*Pyrus malus*), walnut (*Juglans regia*), and pear (*Pyrus communis*).

Beeson (1941) has given a list of 13 food-plants of which four, *Litsaea polyantha*, *Butea frondosa*, *Holarrhena antidysenterica* and *Mallotus philippinensis*, have not been previously recorded.

In addition to taking it from the majority of the plants mentioned by previous investigators, the authors have collected it at Lyallpur, and many other localities in the Punjab, on birdeye (*Withania somnifera*), castor (*Ricinus communis*), "aliar" (*Dodonaea* sp.), *Eucalpytus*, "gurhal" (*Hibiscus rosa-sinensis*), *Convolvulus*

sp., "kurund" (*Chenopodium morale*), "maulsari" (*Mimusops elengi*), lantana (*Lantana camara*), cypress (*Cupressus sempervirens*), "toon" (*Cedrela toona*), terminalia (*Terminalia arjuna*), poinsettia, "chandni" (*Tabernaemontana coronaria*), "bathu" (*Chenopodium album*), "sukhchain" (*Pongamia glabra*), sow-thistle (*Carthamus oxyacantha*), "saunchal" (*Malva parviflora*), banana (*Musa sapientum*), date-palm (*Phoenix dactylifera*), "litchi" (*Nephelium litchi*), "kikar" (*Acacia arabica*) and "jand" (*Prosopis spicigera*). Although *D. stebbingi* feeds on 62 different varieties of plants, it is on mangos that it is a really serious pest.

The Stages of the Life Cycle.

Egg Stage.

Description (fig. 1).—Length 0·9–1·10 mm., greatest breadth 0·65–0·75 mm. Oval (not round as mentioned by Richards & Sharma, 1934), chorion smooth without any sculpturing, shiny pink when freshly laid changing to pale yellow later.

Oviposition.—The females crawl down from their food-plants during May and June and enter the soil to oviposit. The earliest date of oviposition observed at Lyallpur was 7th May in the laboratory and 14th May in the fields. The depth suitable for oviposition is determined by the texture of the soil; in soft, sandy soil eggs are commonly deposited at depths of 2 in. to 6 in.; in rare cases a female may penetrate to a depth of 2 ft. to lay eggs (Rahman, 1940 a); sometimes, where loose soil and dried rubbish were wanting, eggs were laid on the surface of the soil at the base of infested plants. In confinement females laid eggs readily. Some were kept in an incubator at 25°C., and a similar number was reared during April and May in the laboratory, the temperature of which was obtained from a maximum and minimum thermometer. In the case of 10 females, the number of eggs laid at 25°C. varied between a minimum of 195 and a maximum of 372 with an average of 272·7; at 30–33·3°C. the number varied between 23 and 154, with an average of 95·1.

Ovisac.—Eggs are laid within a silken purse—the ovisac (Plate II, *a*)—which is secreted by the female by means of specialised glands 2–6 days before the commencement of oviposition. They are laid by daily instalments, which increase with each successive deposition. A female took 7–16 days to lay its full quota of eggs, after which it died, its ovisac remaining *in situ*.

The size of an ovisac depends on temperature: females kept at 25°C. produced ovisacs measuring 1·05–2·0 cm. in length and 0·8 1·1 cm. in breadth; at 30–33·3°C. they measured 0·75–1·2 cm. in length and 0·6–0·9 cm. in breadth; at 35°C. and over the ovisac was imperfectly developed and in some cases it was not produced at all.

Number of Eggs laid.—The egg-laying capacity of a female varies within fairly wide limits. Stebbing (1902) thought that a female was capable of laying 400–500 eggs, while Lefroy (1908) found that each female laid 300–400, and Dutt (1925) gave 150–210 as an average per female. The writers' collected their data by (1) digging out the dead females from the fields, with their ovisacs *in situ*, on different dates in June and counting the number of eggs contained therein, (2) breeding females in the laboratory and recording the number of eggs laid by each.

In the case of 10 females, the total number of eggs laid per female in the field ranged from 51 to 336, with an average of 149·1, and in a similar number of cases in the laboratory (30–33·3°C.) the number varied as previously stated, between 23 and 154, with an average of 95·1.

Duration of the Egg Stage.—At Benares the eggs hatch after 5 months (Misra & Rao, 1938), but at Lyallpur they take about 8 months. The earliest date hatching was observed was on 7th January and the latest 22nd January ; during 1937, 1938 and 1939 eggs started hatching on the 17th, 14th and 10th of January, respectively.

Nymphal Stages.

There are three nymphal instars in the case of both females and males.

First-instar Nymph (fig. 1).—Length 1·31–2·30 mm., greatest breadth 0·70–1·19 mm. ; elliptical ; general colour chestnut to chestnut brown ; antennae, oculata, rostrum and legs black. Body clothed in setae, those on the margin being large and prominent. Antenna 0·61 mm. long, 5-segmented ; fifth joint longest (0·20 mm.) and clavate ; third smaller than fifth ; second and first equal in length but smaller than third, first segment being much stouter ; fourth segment smallest (0·05 mm.). Compound eyes absent. Ocelli two, button-like, mounted on prominent oculata. Rostrum small, extending to the mesocoxae, 3-jointed ; basal joint narrow, slender and ring-like ; apical joint conical, with a group of sensory setae terminally.

Prothorax fused with head but meso- and meta-thorax distinct. Thoracic spiracles normal. Legs stout, clothed with spine-like setae. Claw stout, curved, with an indefinite denticle near the tip and a pair of setae near the base.

Abdomen 8-segmented, each segment with 2–3 pairs of long, marginal setae 0·20–0·60 mm. in length : these increase in size progressively towards the caudal extremity, the last segment invariably bearing the longest setae. Spiracles, seven pairs, simple, without a pore collar, and located on second to eighth tergum, with a disc pore adjacent to each spiracle. Anal opening surrounded by a chitinised ring and located on the eighth tergum.

Derm membranous, with numerous short hairs and long setae as shown in fig. 1 ; those on sternum arranged in transverse rows. Multilocular disc pores present ; mostly grouped around the anal orifice.

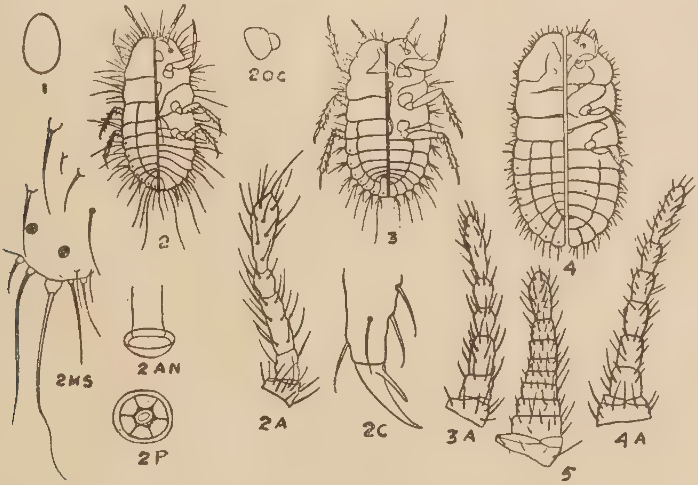


Fig. 1. 1. Egg (×25). 2. First-instar nymph (×35). 2MS. Marginal setae of eighth segment of first-instar nymph (×150). 2A. Antenna of first-instar nymph (×150). 2AN. Anal ring of first-instar nymph (×150). 2P. Multilocular pore of first-instar nymph. 2OC. Ocellus of first-instar nymph with oculata. 2C. Tarsus of first-instar nymph (×150). 3. Second-instar nymph (×20). 3A. Antenna of second-instar nymph (×90). 4. Third-instar female nymph (×15). 4A. Antenna of third-instar female nymph (×68). 5. Antenna of third-instar male nymph—prepupa—(×75).

Second-instar Nymph (fig. 1).—The second-instar nymph resembles the first-instar. Length 2·9-4·7 mm., greatest breadth 1·7–2·6 mm. The anterior margin of the head is distinctly emarginate medially, and the general body colour is bay to orange rufous, with antennae, proboscis, oculata and legs black ; later the body becomes covered with white mealy powder. Antenna 1·03 mm. long, 6-segmented, sixth joint longest (0·30 mm.), and the fifth smallest (0·12 mm.).

Third-instar Female Nymph (fig. 1).—This differs from the second-instar nymph in length 4·55–7·7 mm., greatest breadth 2·5–3·7 mm. ; antenna 1·5–1·6 mm. long, 7-segmented, first joint stoutest, rest gradually tapering towards the seventh, which is the longest and constricted in the middle.

Third-instar Male Nymph (*Prepupa*) (fig. 1).—This resembles the third-instar female nymph but differs in length 4·5–4·9 mm., greatest breadth 2·2 mm. Antenna 1·13 mm. long, 9-segmented. First eight segments short and squat, 9th long and clavate. Ultimate abdominal segment with a slight mesal notch.

Duration of the Nymphal Stages.—The duration of the nymphal period was studied between January and April in 1939, 1940 and 1941. The results in 5 typical instances for each instar showed the duration of the first-instar to vary from 45–71 days ; second, 18–38 ; third-instar female, 15–26 ; and third-instar male 5–10 days. The total duration of the nymphal period, therefore, varied from 77–135 days in the case of the female and 67–119 days in that of the male.

Effect of Temperature on the Duration of Nymphal Stages.

Thousands of newly emerged nymphs were kept on fresh leaves of citrus and rose in an incubator at 25°C. The four stages in the case of the male* were completed in 21, 17, 11 and 8 days respectively.

Habits of the Nymphs.

Young nymphs are strongly negatively geotropic : they climb trees, weeds, grasses, shrubs, bushes, hedgerow-plants, walls, telegraph poles, etc., near their breeding-ground. Once a tree is found they do not leave it easily even in face of obstacles ; 26,094 young nymphs were marked with enamel paint in 31 days to study their persistence in attempting to climb banded trees. The nymphs moved up and down the stem below the band for 6–72 hours before giving up and going elsewhere. Bright, sunny days favoured activity. Their speed was studied, and it was found to average 6 in., 11 in. and 30 in. per minute during first, second and third nymphal stages, respectively. These banding experiments also showed that nymphs visited 3–4 trees before climbing on such low growing weeds as " dodak " (*Carthamus oxyacantha*) etc. From 22nd February to 2nd March, in the experimental garden consisting of mango, citrus, and mulberry, they averaged 1,526 per weed (average of 100 weeds) whilst in the adjacent non-experimental garden consisting of mango, citrus, sissoo, chenopodium, " chandni," mulberry, pongamia, rose, duranta, " aliar," they averaged only 430 per weed (average of 100 weeds).

Before moulting the nymphs wander about on the plant in search of a sheltered place, *e.g.*, cracks in the bark, in which several lie huddled together quiescent and without feeding for 6–14 and 5–12 days in the first and second instars respectively. It is only the first two instars that behave in this manner, because for the third moult the female nymphs do not leave their feeding places, but, after a period of quiescence of 5-9 days, moult and continue to feed and grow in size. The wandering habit of the 1st and 2nd stage nymphs is very strong in February and March. In April 1939, counts were made of the nymphs attempting to climb 20 banded trees, and it was found that the number averaged 89·6 per tree above and 1,733 below the bands. The reason such a large number of nymphs try to climb the trees during April is that they get shaken from the branches before they have completed their feeding and growth. A 9 ft. by 9 ft. tarpaulin was spread under 15 infested trees, and careful counts of the nymphs falling on it within 15 minutes were made; it was found that on an average bugs fell at the rate of 38 per tree per hour.

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* It was not possible to study the effect of temperature on the duration of the female nymph as these nymphs died in the incubator in the third instar for want of sufficient food.

Pupal Stage (fig. 2).

Description.—Length 5·43 mm., greatest breadth 2 mm. Antenna 2·4–4·6 mm. long, 10-segmented, strongly tapering from base to apex. Compound eyes normal; ocelli absent; mouth parts atrophied.

Prothorax distinct from head. Forelegs strongly bent, directed anteriorly. Mesothorax narrow, more than twice as long as prothorax. Wing pads well-developed, 1·5 mm. long. Halteres absent.

Abdomen 8-segmented, first sternum obsolete mesally, posterior margin of the last segment deeply emarginate. Spiracles without pore collars, in seven pairs. Penis and genital sheath only differentiated in older pupae. Anal opening located dorsally on the ultimate segment. Derm with numerous pores, each pore consisting of 8–9 loculi grouped round a circular central area.

Habits and Duration of Pupal Stage.

In the case of the male, a distinct pupal stage intervenes between the nymphal and adult stages. The prepupa (the third-instar male nymph) wanders about for 2–3 days in search of suitable shelter where it then lies motionless in a cottony cocoon (Plate II, *b*); on rare occasions, however, a prepupa was found to rest in exposed situations. The prepupal stage lasts for 3–7 days.

The pupa possesses the power of reconstructing the cocoon should it be removed and repairing it should it be damaged in any way. The duration of the pupal stage is 9–15 days in the Punjab.

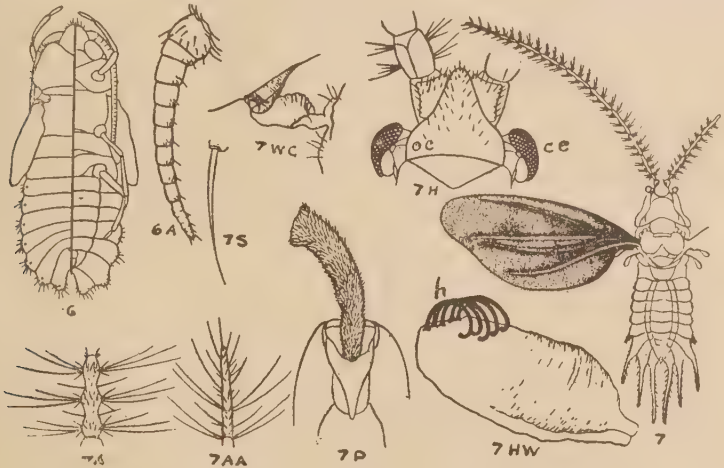

Fig. 2. 6. Pupa (×22). 6A. Antenna of pupa (×28). 7. Adult male (×18). 7HW. Hind wing (Haltere) of male (×190); curved and apically knobbed setae (h). 7P. Genitalia of male. 7A. Third antennal segment of male. 7AA. Tenth antennal segment of male. 7H. Head of male; compound eye (ce), ocellus (oc). 7WC. Wing coupling apparatus of male. 7S. Long seta of male.

Adult Stages.

Male (fig. 2).

The adult male was first described by Green in 1903. We re-describe it below more fully.

Body elongate, 4·6 mm. long, 1·6 mm. broad, dull red. Antennae, eyes, occiput, legs, wings, pleural, notal and sternal plates brownish-black. Apex of head triangular. Mouth-parts atrophied. Antenna 10-segmented, 5–6 mm. long ; first segments short (0·19 mm.), second 0·27 mm. long with a whorl of setae, third to ninth 0·68 mm. in length and similar in structure, trinodose, with three distinct whorls of setae on each node, tenth longest (0·84 mm.) with four whorls of setae, the distal pair of which are confused. Compound eyes very prominent. Ocelli situated adjacent to the compound eyes, two, surrounded by black oculata.

Prothorax white membranous, with two longitudinal black lines situated dorso-laterally ; lateral margins ampliated. Mesothorax well developed ; pleural, notal and sternal plates highly chitinised ; mesoscutum with an anterior big lunate patch and two small patches posteriorly. Metathorax very much reduced, membranous, with a patch on the notum ; pleural, notal and sternal plates absent. Front wings 4·9 mm. long, 2·2 mm. broad, dark in colour with a pocket towards the base of the hind margin. Venation reduced consisting of faint Sc, and prominent Rs+M. The latter form a fork which is anteriorly and posteriorly bounded by black lines. Two conspicuous white creases terminate short of the caudal margin. Hind wings reduced to small, flattened, halteres 0·55 mm. long, 0·23 mm. broad, with 5–9 curved apically knobbed setae (h). Meso- and meta-thoracic spiracles distinct.

Abdomen membranous, 8-segmented ; median area tumescent ; first five segments normal, usually the fifth to eighth each bear a pair of fleshy tassels which are progressively longer towards the caudal extremity, but in some individuals the first pair is either vestigial or absent ; ultimate segment strongly notched mesally. Anal opening apical, surrounded by a chitinous circular ring. First abdominal sternum obsolete mesally, second to sixth normal, seventh and eighth narrow mesally forming a semicircle round the genital sheath. Penis very stout and about 2 mm. long, thick basally and tapering towards apex when *in situ* (vice versa when extruded), densely clothed with short reversed spines. Male genitalia enclosed in a funnel-shaped penis sheath (7P), which projects a little beyond the posterior margin ; it is broad at the base and has a semicircular cut on the dorsal side, tapers strongly towards the caudal end and terminates in a rounded tip bearing sensory pores. Hinged to this sheath ventrally is a rectangular plate-like ventral valve which is usually thin and flattened. Spiracles, seven pairs, simple.

Body clothed with setae of moderate size, except at the margin, and some longer setae around the genitalia (fig. 2, 7S).

Female (fig. 3).

Elliptical, with numerous minute hairs and circular pores both dorsally and ventrally, covered with white mealy powder, 14–16·5 mm. long, 7–8·5 mm. broad, body margins somewhat flattened and furnished with setae. Antenna brownish-black, 8-segmented, 2·3–2·6 mm. long, terminal segment longest and basal broadest, each segment bearing numerous setae. Compound eyes absent, ocelli two, simple, transparent, surrounded by black oculata. Rostrum elongate, conical, distinctly 3-segmented, furnished with sensory setae apically.

Legs brownish-black, stout, ventral aspect of tibiae and tarsi, and the inner surface of the distal half of femora bearing stout spine-like setae ; claw single, stout, curved with its inner aspect often roughened, but without definite denticles.

Thoracic spiracles, large, with bar and a few pores near entrance.

Abdomen 8-segmented ; first three terga almost straight and parallel, fourth and fifth bent towards caudal end, sixth semicircular, narrow medially, seventh broadly U-shaped, enclosing the V-shaped eighth tergum which bears the anus ; anal opening dorsal, napiform, surrounded by setae and heavily chitinised at its inner extremity. First sternum obsolete, second and third sterna straight and parallel, fourth to eighth curved caudally with a progressive increase in the bend. Genital opening transverse, slit-like, located on the seventh sternum. Abdominal spiracles, seven pairs, without pore collar, located on second to eighth terga ; each with a short cylindrical tube, furnished with spiral thickenings like taenidia and an expanded inner extremity.

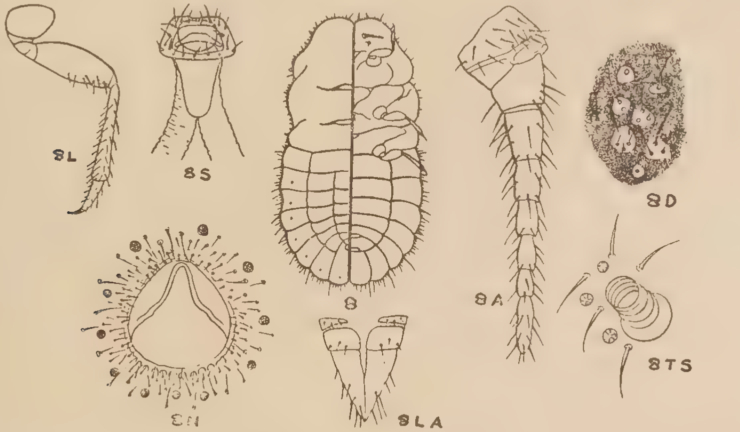

Fig. 3. 8. Female adult (×8). 8A. Antenna of female (×65). 8D. Derm membrane of female (×160). 8LA. Labium of female. 8L. Leg of female. 8N. Anal orifice of female (×175). 8S. Thoracic spiracle of female (×65). 8TS. Abdominal spiracle of female (×175).

Derm furnished with multilocular disc pores having 5–8 (usually 6) loculi, a cluster of which occurs around the genital aperture ; without spines, but with setae of moderate size which are replaced by relatively very large and conspicuous setae along the body margin. Chitinisation of derm slight with large circular to oval areoles enclosing multilocular pores and setae.

Longevity of Females.—The females are fairly long lived, and 15 individuals kept under observation in April and May of 1940 and 1941, from emergence to death, were found to live from 22 to 47, with an average of 36·2 days. Males on the other hand live from a few days to a week.

Phototropic Response of Males.—Six hurricane lanterns were put up in a garden at Lyallpur at 50 feet intervals, regularly, from 1st to 22nd April. Each lantern was placed on a brick lying in the middle of an earthen pan filled with water carrying a film of kerosene. 272 males were attracted giving an average of two males per lamp per night. Thus the males are practically negatively phototropic.

Copulation.—According to Lefroy (1908) " a female of *Monophlebus stebbingi* var. *octocaudata* is generally fertilized from one to three weeks after the general moulting period." In the case of *Drosicha stebbingi*, copulation took place soon after emergence. The adults paired only from the second week of April to the first week of May, and copulation lasted 4–10 minutes only.

Pre-oviposition Period.—To determine the pre-oviposition period, 18 freshly mated females were collected from the garden on different dates and kept in the laboratory singly in glass dishes which were half filled with loose moist soil. The period was found to vary from 15–36, with an average of 25·3 days.

Downward March for Oviposition.—The females, after the third moult, crawl to the terminal portions of the branches where they congregate in dense clusters and secrete copious honey-dew which, falling on the vegetation below, imparts to it a wet, glistening appearance. They develop rapidly to a large size within 13–22 days of fertilisation. The fertilised females usually start their downward march to oviposit at the beginning of May. The stream of descending females reaches its peak during 2nd and 3rd week and then begins to subside, stopping altogether by the middle of June.

Dutt (1925) has stated that females ready for oviposition crawled along the stem to reach the soil.

Some fertilised females drop to the ground and observations carried out as described on p. 201 in the case of 15 trees showed that an average of 76 such females fell per hour. The crawling females were either hurled off the trees by wind or fell off.

Effect of Temperature on Oviposition.—This was observed in the case of 400 females, 200 of which were kept at 25°C. and the remainder at 30–33·3°C. It was found that in the former case 98·5 and in the latter 74 per cent. laid eggs.

Seasonal Prevalence.

The seasonal prevalence can be expressed as follows :—

June–January	Eggs in soil.
January–beginning of March ...	First-stage nymphs only present.
March	Second-stage nymphs predominate.
End of March–mid April	Male pupae and third-stage female nymphs common.
Mid April–beginning of May ...	Males and females common ; copulation takes place.
First week of May–end of June ...	Males die ; females enter soil, oviposit and die.

INSECTS FEEDING ON HONEY-DEW.

D. stebbingi produces large quantities of honey-dew which is greedily sought by many insects, a list of which, collected in 1938–39, identified by the Imperial Entomologist, New Delhi, is as follows :—

Serial No.	*Name*		
1.	*Calliphora grahami*, Aldr.	Calliphoridae ...	Diptera
2.	*Chrysomyza aenea*, F.	Ortalidae... ...	,,
3.	*Lasiopticus latimaculatus*, Brun.	Syrphidae ...	,,
4.	*Syrphus balteatus*, Deg.	,, ...	,,
5.	*Sepsis* sp.	Sepsidae	,,
6.	*Musca* sp.	Muscidae... ...	,,
7.	*Cynomyia* sp.	,, ...	,,
8.	*Tachydromia* sp.	Empidae... ...	,,
9.	*Phytomyza* sp.	Agromyzidae ...	,,
10.	*Chrysis* sp.	Chrysididae ...	Hymenoptera
11.	*Holcomyrmex glaber*, André	Formicidae ...	,,
12.	*Acantholepis frauenfeldi* var. *bipartita*, Smith	,,	,,
13.	*Camponotus sericeus*, F.	,, ...	,,
14.	*Oxycarenus laetus*, Kirby	Lygaeidae ...	Hemiptera

NATURAL ENEMIES.

Parasites.

Lefroy (1908) mentions a Dipterous parasite, and a Hymenopteron which he considered a hyperparasite of it. Dutt (1925) also mentions a Dipterous parasite. The authors found the following parasites of the nymphs and pupae :—

An unidentified Dipterous parasite is fairly common in March and May in the infested gardens of Lyallpur. From 371 second- and third-instar nymphs and pupae of *D. stebbingi* collected on the 25th March, and kept in the laboratory, 39 adult parasites emerged between 5th and 15th April, which represented a 10·5 per cent. parasitisation.

The parasite completed its life-cycle in 25–50 days : egg stage 4–9 ; larval stage, 15–27 ; pupal stage, 6–14. Eggs were laid singly both in the abdomen and the thorax of the host. The parasite larvae fed on the alimentary canal of the host and in due course changed into an exarate type of pupa. Only one parasite grub developed in each host.

The newly parasitised nymphs were found to become increasingly sluggish in their movements as the parasite developed, until they were entirely incapable of movement. At the same time parasitised individuals developed a swelling and blackish colouration in their abdominal regions. The adult parasites escaped through neatly cut circular holes in the abdomen or thorax of the host.

A species of *Phygadeuon* (Ichneumonidae, Cryptinae) (Plate II, *c*) was found to oviposit during April and May in the second- and third-instar nymphs only. It did not breed in the laboratory.

Predators.

Insects : Stebbing (1903) mentioned an unidentified Coccinellid that was predacious on *Monophlebus.* Lefroy (1908) found *Aulis vestita,* Muls., and Dutt (1925) *Sumnius renardi,* Weise, feeding on this pest. The following insects preying on the nymphs were found by the authors in the Punjab :—

Coleoptera : *Coccinella septempunctata,* L., *C. undecimpunctata,* L., *Hippodamia variegata,* Goeze, *Chilomenes sexmaculata,* F., and *Adonia doubledayi,* Muls.

Neuroptera : The larva of *Chrysopa scelestis,* Banks. /e

Birds : The common babbler, *Argya caudata caudata,* Dumont (Timalidae) fed upon the females and nymphs in March and April at Lyallpur.

CONTROL MEASURES.

Destruction of Eggs.

In the past the destruction of the eggs by digging them out with spades from the soil has been recommended. This was tested but the results were not encouraging because many females wander into the hedges, débris, etc., away from the infested orchard to lay eggs.

Trials with various Types of preventive Bands.

Dutt's Band.—Dutt (1925) suggested methods of preventing the mature females of *Monophlebus stebbingi* var. *octocaudata* from descending the trees and entering the soil for oviposition. He recommended the use of bands of sann-fibre soaked in a mixture of crude oil emulsion and coal tar in equal parts (Plate II, *d*). This recommendation was tested for two years in two heavily infested gardens, one at Lahore and the other at Lyallpur.

Three hundred infested trees were banded so as to prevent the females from descending and entering the soil for egg-laying.

Nineteen trees (with girths varying from 1 ft. 2 in. to 5 ft. 3 in.) were selected at random and counts were made of the mealybugs which successfully crossed the bands 48 hours after their application. The records for 11 of the 19 trees banded showed the number successful in crossing the band per hour 48 hours after application to vary between 12 and 415 with an average of 100.

Cotton Band.—Lal (1918–19) reported that fluffy cotton bands (Plate II, *e*) were quite efficacious in checking the upward march of nymphs, but Husain (1920) found that they were not so. The authors found them very effective, but squirrels and sparrows pilfered the cotton to line their nests to such an extent that they were very soon rendered useless. Rain also reduced their effectiveness very considerably.

Grease Band.—Stebbing (1903) suggested that a grease band might prove useful in checking the downward march of the fertilised females. Lal (1918) found them effective. They were tested on a field scale at Lyallpur with a second band of Tacko* 3 ft. above the grease band in order to trap any bugs that might cross it. Counts were made after every 24 hours and it was found that 151–204 mealybugs crossed in 24 hours. The band became less effective daily and was useless at the end of a week.

Grease-coal Tar Band.—Stebbing (1903) also suggested a grease-coal tar band (prepared by heating together equal quantities of these two ingredients) for preventing the mealybugs from alighting from the trees. This band was tried out in the same manner as the grease band and it was found that 114–161 mealybugs crossed in 24 hours.

Coal Tar Bands.—Coal tar either alone or diluted with kerosene oil is commonly used by orchardists for banding their fruit trees in the Punjab. A 9 in. broad band of pure coal tar was applied to 21 trees during January, February, April and May of 1939 and 1940. The band remained effective for 4–5 days in January and February and 2 3 days in April and May, afterwards it dried up and the mealybugs crossed easily. When diluted with kerosene oil, it remained effective for 3–4 days in January and February and 1–2 days in April and May. It was further found necessary to apply the coal tar bands to the trees twice a week during January and May. The cost of a single application of a 9 in. broad band of coal tar was Rs. 2/8/– per hundred trees.

Coal Tar-Glue Band.—Stebbing (1903) suggested that grease bands to be effective should be composed of a mixture of tar and glue mixed in such proportions as to ensure a sticky band. This did not show any improvement on the coal tar band at Lyallpur.

Coal Tar-Rosin Band.—To prepare this mixture, coal tar and rosin were taken in the ratio of 1 : 3. Coal tar was heated over a slow fire and powdered rosin added in small quantities and stirred well.

The mixture was applied as a 3–6 in. broad band round the stem from January to April (Plate II, *f*). Within 24 hours of its application only 1–6 mealybugs crossed, but during the next 48 hours 79–96 crossed, showing that the band had already become ineffective.

Other sticky Bands.—Rosin-" toria " oil band (Chopra, 1928) ; rosin-" neem " oil and vaseline band (Richards & Sharma, 1934) ; rosin-castor oil band (Beeson,

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* A proprietary material which is sold at Rs. 2/– per lb. Its efficacy was tested at Lyallpur and Lahore during 1939–41, and it was found to remain effective for about three months in summer and six months in winter. One pound of it was sufficient for 8–12 trees, and this gave a cost of Rs. –/2/8—Rs. –/4/– per tree, which is very high.

1941), rosin-fish oil band, rosin-linseed oil and rosin, rosin-oil band (quantity of rosin used in all these bands varied from 1 to 4 parts) were all tried but proved ineffective, because they dried up 2–4 days after application.

Black Oil Cloth Bands.—Rahman (1940 b) recommended a 2 in. wide strip of black oil cloth for preventing young mealybugs from climbing the trees. Oil cloth presents a glossy surface on which the nymphs are unable to get a foot-hold. In 1939 eighteen trees were selected at random and divided into six groups of three each. Each group of trees was banded with a strip of oil cloth of a definite width which ranged from ½ in. to 4 in.; 15–33, 8–11, 2–4, 0·5–1 nymphs crawled over the bands of ½ in., 1 in., 1½ in. and 2 in. width respectively per week.

In 1940, as a result of this experience, oil cloth bands of 2 to 2½ in. width only were again tested on eleven trees over a period of ten weeks.

Banding (Plate II, *g*) was done in the middle of February, but the observations were started in the fourth week of February, and were continued until the first week of May. The results are presented below. (Each tree had a second band of Tacko to trap the bugs which had crossed the oil cloth strip.)

TABLE I.

Average number of nymphs crossing a 2-in. wide band of oil cloth per week.

Feb.	March				April				May
4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st
10·4	11·0	26·7	4·7	14·4	7·0	4·4	2·8	2·8	1·3

It will be seen from the foregoing table that the number of nymphs crossing the band during February and March is higher than in April and May.

The explanation for this is that most probably the pulvilli of the young nymphs are slightly better suited to maintain a foothold on the slippery surface and at the same time the force of gravity exerts less influence than in the case of the second- and third-instar nymphs.

Namhar.—It is well known that sulphonation of castor oil by concentrated sulphuric acid produces a substance with gummy characteristics. According to Lewkowitsch (1915), the properties of the product thus formed depend upon the strength and amount of acid added on the one hand and temperature, time of heating and pressure on the other. According to Scheiber (1936) the phenomenon is one of dehydration and polymerisation of ricin-oleic acid, which is the main constituent of castor oil.

Since time for aeration is needed in the process, the products improve in gummy properties on keeping for two to three weeks and on constant stirring.

With a view to evolving a gummy material which, in addition to the properties mentioned above, would be cheap and easily prepared as well as retaining its sticky properties for a longer period, a sulphonated product was prepared in accordance with the following formula. This has been called "Namhar" and it has proved most effective in preventing the mealybugs from climbing the trees.

Part A	Conc. Sulphuric Acid Commercial sp. gr.=1·82 or over	½ lb. by weight
	Castor oil	1 lb.
Part B	Rosin	2½ to 3 lbs.
	Axle grease	2 lbs.
	*Glycerine (commercial)	2 ozs.

---

*5–10 grams of unslaked lime or calcium chloride can also be added.

Part A.—The castor oil and concentrated sulphuric acid are mixed and stirred vigorously. The mixture sets like jelly on cooling and is kept for 14 days, being occasionally vigorously stirred.

Part B.—The axle grease is heated and the powdered rosin added gradually. During heating the mixture is kept well-stirred, and when the rosin has dissolved thoroughly, it is removed from the fire and the glycerine added. The whole is stirred well and allowed to cool.

A and B are mixed as required for use. The effectiveness of this sticky material was tested on 1,239 mango trees between 1940 and 1942. The results were as follows (only 12 cases cited for the sake of brevity).

TABLE II.

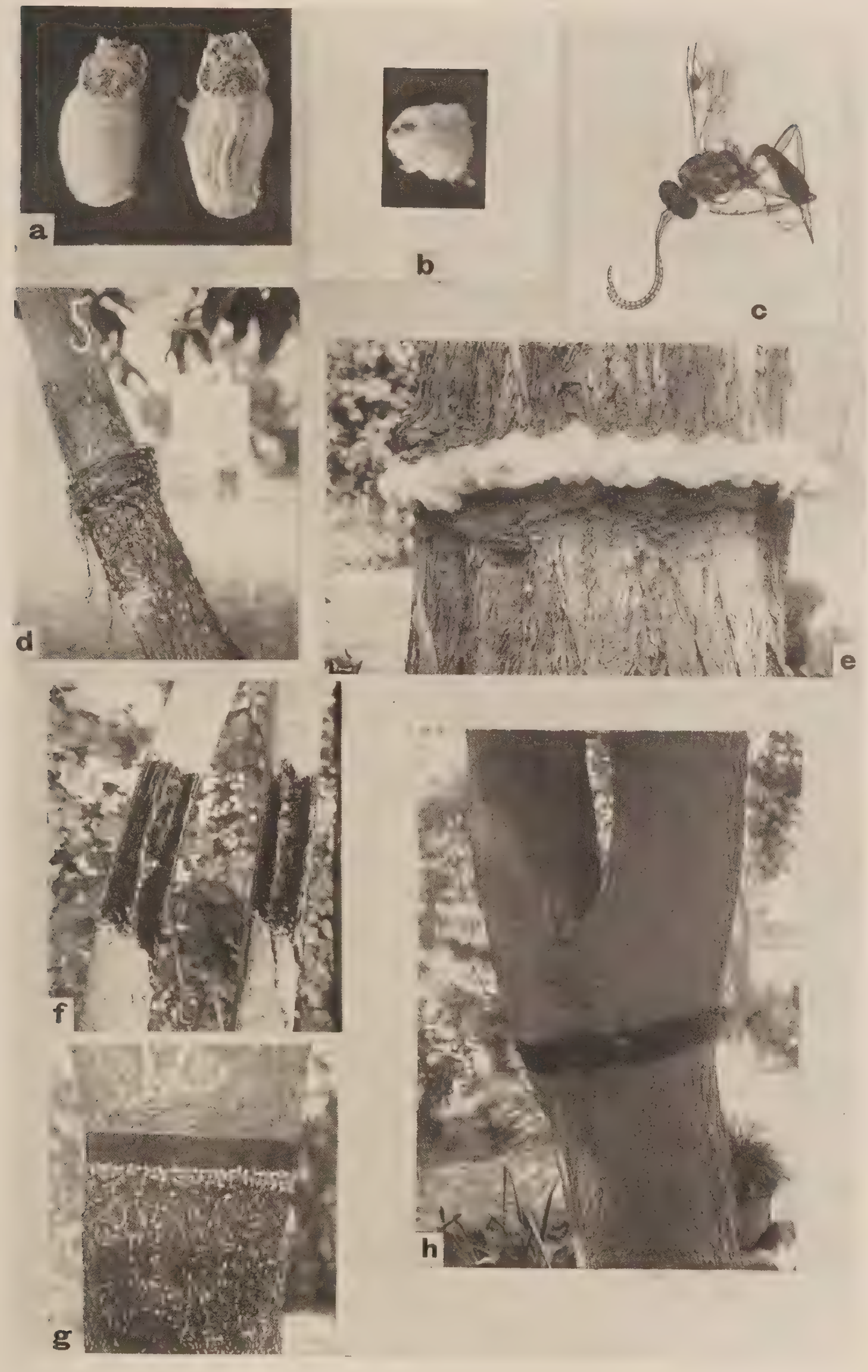
No. of tree	Date of application	Date on which a nymph crossed the Namhar band	Remained effective for (days)	Remarks
5	19.xii.40	1.iii.41	72	Stem in shade
8	19.xii.40	7.iii.41	78	Stem in shade
9	19.xii.40	11.ii.41	54	Stem partly exposed to sun
10	19.xii.40	1.ii.41	44	Stem partly exposed to sun
12	22.xii.40	18.ii.41	58	Stem partly exposed to sun
14	22.xii.40	20.ii.41	60	Stem in shade
15	24.xii.41	8.ii.42	46	Stem partly exposed to sun
16	24.xii.41	25.ii.42	63	Stem in shade
19	24.xii.41	18.ii.42	56	Stem in shade
20	5.i.42	7.iii.42	51	Stem in shade
27	5.i.42	2.ii.42	42	Stem partly exposed to sun
39	5.i.42	18.ii.42	44	Stem partly exposed to sun

It will be observed from the above table that from December to March the Namhar band remained effective for 78–51 days in shade and for 58–42 days when partly exposed to sun, and during this period not a single mealybug succeeded in crossing. One lb. of this material was found to be sufficient for 10–20 trees, according to girth, for the first application and for 15–20 trees for the second application. Two applications were found necessary during the season. In the case of trees which had their stems exposed to the direct rays of the sun, one or two additional coatings were required. The cost of the first coating was found to be 4½ pies and that of second and third coatings 6–9 pies, per tree.

SUMMARY.

The giant mealybug, *Drosicha stebbingi*, is a serious pest of wide distribution in the Punjab. It feeds on 62 plants of which mango, citrus, " ber " and guava suffer the most.

All stages of the insect are described in detail.



Drosicha stebbingi (Gr.) (a) females with ovisacs (x about 1); (b) pupal cocoon; (c) *Phygadeuon* sp., adult; (*d*) Dutt's band; (e) Cotton band; (f) Coal tar-rosin band; (g) Oil cloth band (after Khan A. Rahman 1940); (h) Namhar band.

A female can lay up to 372 eggs. These are laid in May and June in an ovisac at a depth of 2–6 ins. in the soil. The egg stage lasts about 8 months at Lyallpur. The females pass through three, and the males through four, nymphal instars, which are completed in 77–135 days in the case of females and 76–134 days in the case of males as follows :—Female : First-instar 45–71, second-instar 18–38, third-instar 15–26. Male : First-instar 45–71, second-instar 18–38, third-instar 5–10. The male pupal stage occupies 9–15 days.

The general habits and behaviour of the pest are described in detail.

Fourteen different species of insects are listed which have been found feeding on the honey-dew produced.

The mealybug is parasitised by *Phygadeuon* sp. and an unidentified Dipteron and is preyed upon by five Coccinellids, a species of *Chrysopa*, and a bird.

The various control measures suggested by previous investigators were tried out on a field scale, but did not give satisfactory results. Black oil cloth and a new sticky material -" Namhar "—proved the most effective types of banding. The formula and method of preparing the latter material are described in detail.

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TWO NEW GALL MIDGES FROM MAURITIUS.

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Specimens of a *Stenodiplosis* were received early in 1942 from Mr. A. Moutia labelled "no. 73, ex inflorescence of *Stenotaphrum dimidiatum*, Mauritius (Reduit), xii.1940." In a subsequent letter, dated 25th May, 1942, Mr. Moutia stated that the midges were reared in the laboratory from material collected in the fields. He also gave the information that the grass, *S. dimidiatum*, forms about 40–50 per cent. of the pastures in Mauritius and, though its main mode of reproduction is by its root stock and cuttings, the dispersion of its seeds may to some extent help in bringing a profuse and thick layer of growth.

The midges have been compared with specimens of *Stenodiplosis geniculati*, Reuter, from both England and New Zealand, with *S. geniculati*, Reuter, var. *dactylidis*, Barnes, from New Zealand, and with specimens of *S. panici*, Rohd., from the Volga area, Russia. It is obvious that the midges from Mauritius are a distinct species, and they are therefore here described as new.

Stenodiplosis stenotaphri, sp. n.

♂. *Length* about 2 mm. *Antennae* 2+12, stem of third flagellar segment about twice as broad as long, neck about as long as broad or very slightly longer; stem of 10th flagellar segment about as long as broad, neck about twice as long as broad; 12th flagellar segment often trinodose, the basal stem about as long as broad, the distal stem often quite distinct. *Palpi* triarticulate. General colour apparently yellowish brown with darker thorax. *Wings* clear, narrow, about three times as long as broad, third vein reaching margin just beyond apex of wing. *Genitalia* of typical *Stenodiplosis* structure.

Cotypes: Cecid. 4280–6, 4302–6.

♀. *Length* about 2 mm. *Antennae* 2+12, neck of third flagellar segment nearly six times as broad as long, neck of 10th flagellar segment about three times as broad as long, 12th segment with a distinct knob-like prolongation. *Abdomen* more honey-yellow than in male. *Ovipositor* long aciculate, striate.

Cotypes: Cecid. 4288–93, 4307–11.

Pupal case (Cecid. 4287). Thoracic, wing and antennal sheaths not so dark as in *S. geniculati*, Reuter.

Habitat: Inflorescence of *Stenotaphrum dimidiatum*.

Locality: Reduit, Mauritius.

S. stenotaphri, sp. n., is very similar to *S. panici*, Rohd., but may be distinguished by the more squat and less elongated stems and necks on the flagellar segments of its antennae. Thus the stem of the third flagellar segment in the male of *S. panici* is about half again as broad as long and the neck slightly longer than broad, whereas in *S. stenotaphri* the stem is about twice as broad as long and the neck is about as long as broad or very slightly longer. In the female the neck of the third flagellar segment in *S. panici* is about three times as broad as long, but in *S. stenotaphri* it is nearly six times as broad as long. Both these species have shorter stems and necks on the flagellar antennal segments than either *S. geniculati*, Reuter, or *S. geniculati* var. *dactylidis*, Barnes (*see* Barnes, H. F. 1940. The gall midges attacking the seed-heads of cocksfoot, *Dactylis glomerata*, L.—Bull. ent. Res., **31**, pp. 111–119).

Specimens of a *Contarinia* were also received early in 1942 from Mr. A. Moutia labelled "no. 74, ex *Citrus* blossoms, Mauritius (Beau Bassin), ix.1941." Subsequently, a tube of larvae which had been collected in September 1941 was received from the same source. The following information is taken from a letter, dated 25th May, 1942, from Mr. Moutia. The insect was collected and reared from the flowers of various species of citrus (*Citrus maximus, C. trifoliata, C. medica*). The larvae were found very abundantly in the flowers, as many as one hundred being obtained per flower. Many of the infested flowers were unable to develop, most of the reproductive organs appearing shrivelled, and dropped prematurely. In October 1941 over 25 per cent. of them were attacked. Adults emerged 10–12 days after young larvae had been collected, and the pupal stage only lasted two days.

This midge is considered to be new and is described below as *Contarinia citri*, sp. n., the Citrus Blossom midge.

Contarinia citri, sp. n.

♂. *Length* about 1·5 mm. or less. *Antennae* 2+12, normal *Contarinia* structure, with distinct stems and necks of about equal width; stem of third flagellar segment nearly half again as long as broad, neck about three times as long as broad and distinctly longer than stem; stem and neck of 10th flagellar segment about four times as long as broad, neck only very slightly longer than stem; 12th flagellar segment with stem about four times as long as broad and about one-quarter again as long as the terminal elongation, which is pubescent, of uniform width and as long as terminal node, the latter is two-and-a-half times as broad as elongation. *Palpi* quadriarticulate; basal segment small, quadrate; second about twice as long as broad; third narrower, about four times as long as broad; distal segment slightly narrower and longer than third, about five times as long as broad. *Genitalia* of typical *Contarinia* structure.

Cotypes: Cecid. 4294–7, 4312–6.

♀. *Length* about 1·5 mm. or more. *Antennae* 2+12; first flagellar segment three to four times as long as broad, no neck, fused with second; second about two-thirds the length of first, about twice as long as broad, short transverse neck; third flagellar segment slightly shorter, shortest in flagellum, neck transverse, about twice as broad as long; succeeding segments slightly longer and with necks gradually increasing in length and decreasing in width; 10th flagellar segment slightly longer than third, neck about twice as long as broad, much narrower than that of third; 12th about as long as 10th, with distinct setose prolongation, about twice as long as broad. *Ovipositor* aciculate, very long and extensile as usual in *Contarinia*. Otherwise about as in male.

Cotypes: Cecid. 4298–4301, 4317–21.

Larva (Cecid. 4444–8). Normal, bifid anchor process.

HABITAT: *Citrus* blossoms.

LOCALITY: Beau Bassin, Mauritius.

No other gall midge has been described from *Citrus* blossom. Two other species of gall midges recorded from *Citrus* are *Asynapta citrinae*, Felt (1932) from grape fruit and the larvae of an unidentified gall midge found at the base of the calyx on imported oranges in England by Bagnall and Harrison (1922). The latter species is probably predatory rather than phytophagous. The larvae of *A. citrinae* were found by G. N. Wolcott in grape-fruit twigs at Isabella, Porto Rico in 1931. Felt described the larvae and adults of both sexes.

Attention is drawn to the need for taking every possible precaution to prevent the Citrus Blossom midge from extending its geographical range. Two other gall midges of the genus *Contarinia* fall into the same category of potential, but as yet local, serious fruit pests, namely the Tomato Flower midge (*C. lycopersici*, Felt) and the Apple Blossom midge (*C. mali*, Barnes). The latter is known only from Japan, while the former has occurred in the West Indies (St. Vincent, Trinidad and Barbados) and probably also in Hawaii.

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THE REMOVAL OF INSECT PESTS FROM STORED PRODUCTS BY MEANS OF BEHAVIOUR STIMULI.

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Introduction.

The control of insect pests attacking stored food products involves various preventive measures and the killing of the pests *in situ*. Only in certain cases is the mechanical removal of the killed insects either necessary or practicable. So far, little attention has been paid to the possibility of removing the living pests by exploiting responses of the insect to particular stimuli in cases where mechanical separation is impossible. This method is worth attention when the pest species is fairly mobile and when the quantity of infested products is not too large. To deal effectively with any particular pest by taking advantage of the insect's response to various stimuli, we need to know those stimuli that evoke an " all or none " reaction. If the information is not already available, an empirical survey of the animal's behaviour will reveal the most effective stimuli. Those which can be produced under warehouse conditions are selected and apparatus designed to permit a continuous separation process is devised. Such apparatus involving the appropriate stimuli must be simple enough to assemble at the site of the infested store. We describe here how a de-infestation problem may be tackled along these lines.

Methods.

Several cases of the presence of *Silvanus surinamensis* in tea were reported. The beetles were not breeding in the tea but had entered from adjacent infested products. To remove the insects from the tea without harm to the latter, two possibilities existed :—

(*a*) Removal of the insects after they have been killed.

(*b*) Causing the beetles to leave the tea by exposing them to appropriate behaviour stimuli.

Since tea varies widely in density and particle size, much of it being of size and density similar to that of *Silvanus*, mechanical separation would be extremely difficult and impracticable for small scale infestations. Hence the second alternative was chosen.

A rough survey of the behaviour of *Silvanus surinamensis* was carried out. Since " all or none " reactions were being sought for, detail and refinement of primarily academic interest were avoided. The reactions are dealt with in order.

Light.—If *Silvanus* is tipped on to a flat surface in a room, it runs away from the direction of incident light. Shallow, circular dishes were blackened on the inside and arranged so that one-half of the dish was illuminated from above while the other half was in darkness. When beetles were placed in such dishes, they showed a striking preference for the dark side. This was true of both dark and light adapted animals. Beetles placed in glass tubes illuminated from only one end, tend to collect at the end furthest removed from the source of light. A long rectangular glass sided box was set up so that the only source of light was a narrow beam entering at one end. Several hundred beetles were dropped, a few at a time, through a small hole in the roof ; 98 per cent. showed a strong photo-negative reaction.

Temperature.—100 beetles were introduced into a well insulated temperature gradient at equilibrium with the room temperature. A small quantity of tea was placed at the end which was later to form the warm end of the gradient. After an interval of 15 hours, all but a few of the beetles had buried themselves in the tea. The apparatus was set going and as the temperature at the hot end rose to about 37°C., the beetles came out and ran rapidly over the surface of the tea. Between 37°C. and 40°C. all the beetles left the tea and ran down the gradient to a cooler region. When their apparently random movements carried them into too hot a part of the gradient, the beetles showed a violent avoiding reaction. The temperature at the hot end of the gradient rose from 15°C. to 42°C. over a period of one hour with an approximately linear relationship between rise of temperature and time.

A very rough estimate of thermal death point showed that, under ordinary conditions of humidity and with a fairly rapid rise of temperature (22°C. to 50°C. in 55 minutes), *Silvanus* falls into a heat rigor at approximately 50°C. The beetles die if kept at this temperature but recover if the temperature is immediately lowered.

Mechanical Activation.—When resting beetles are shaken or mechanically stimulated, they start to run about, a considerable and variable period elapsing before they come to rest again in the absence of stimulation. As mentioned earlier, if tipped out on to a flat surface, they run quickly in a fairly straight line, the direction depending on the position of the light source.

Contact.—The collection of *Silvanus* in an isolated heap of tea may be due to a smell or a contact response or to a combination of the two. Experiments with clean, sterile glass wool showed that *Silvanus* has a very pronounced contact response under normal laboratory conditions of temperature and humidity. There is also evidence for a positive smell reaction to tea. Hence it is likely that both responses cause the beetles to collect in tea. No effort was made to find specific attractants or repellents since such substances would almost certainly impart an undesirable flavour to the tea.

Gravity.—No well marked response to gravity was observed. When beetles are dropped on to a board tilted at 30°, with very dim overhead illumination, they usually describe a series of irregular circles. When the insects are kept in upright cork stoppered vials, the majority come to rest immediately below the cork. It is possible that a negative reaction to gravity is a component of this response, but it seems likely that contact and smell reactions are more important.

Air Currents.—There is no evidence of orientated locomotion with respect to air currents.

Having completed the rough survey, we need to devise a simple technique which permits the combined use of the three most effective stimuli, namely light, heat and mechanical activation. A conveyor belt forms the basis of the method described here, since it allows a continuous separation process. The tea, containing the beetles, is fed on to the surface of the belt in an even layer not exceeding ·2 inch, leaving on either side of the belt an uncovered margin of 4 inches. The only source of light is from a row of strong electric lamps which are arranged down one side of the belt so as to illuminate both the upper and lower side. Heat is applied from below so that the upper surface of the belt never rises above 42°C. to 43°C. An oil bath is placed beneath the belt. As tea is spread on to the belt, the beetles are mechanically activated, the heat drives them to the surface and the unilateral illumination causes them to run across the surface to the dimmer side where most of them fall off the belt and may be trapped in the oil bath. The remaining beetles are confined to the extreme edge of the margin since both upper and lower surface of the belt are laterally illuminated, and may be removed by a suction pump (of the vacuum cleaner variety) just before the de-infested tea is collected at the end of the conveyor. A small scale model of the apparatus described here has been used in the laboratory to remove not less than 90 per cent. of the beetles infesting small samples of tea.

The speed of any separation process involving behaviour stimuli is limited by the speed at which the animals walk and the initial distance of the insects from the point of removal. The rate of travel of a belt can be roughly estimated from the formula

$$r = \frac{a\ c\ \mathrm{Cos}\ \theta}{b}$$

where c = effective length of the belt
θ = the angle the beetles' direction makes with the width of the belt
b = width of the band of tea plus width of one margin, *i.e.*, maximum distance of the beetles from the point of removal
a = rate the beetles walk
r = rate of travel of the belt

Most of the beetles run in an approximately straight line across the width of the belt. There exists, however, some individual variability which does not lend itself to precise estimation. So it is best to allow a safe margin of error and put $\theta = 45°$. Hence

$$r = \frac{c\ \ a}{b\sqrt{2}}$$

Since *Silvanus* runs over warm tea at approximately one inch per second, the rate of travel of the belt in feet per second can be calculated from the expression $r = \frac{c}{12\ \ b\sqrt{2}}$. Thus with a conveyor travelling on rollers 15 feet apart and with a width of 1 foot 8 inches, the rate of travel can be estimated as ·66 feet per second. It must be remembered that only 1 foot of the width of such a belt is effective on account of the margins. Since we know the depth and area of the tea, and since 1 lb. of loosely packed tea occupies about 73 cubic inches, we can calculate the weight of tea de-infested per hour as approximately 8½ cwts. By using longer belts the process could naturally be speeded up. The above formula and calculations should be considered as a useful guide rather than an absolutely exact measure of the separation process.

Summary.

A continuous method is described of separating adult *Silvanus surinamensis* from infested tea by means of an apparatus involving three behaviour stimuli, namely, light, heat and mechanical activation.

Acknowledgments.

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THE PROPAGATION OF INSECT PARASITES ON UNNATURAL HOSTS.

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1. Introduction.

When an insect parasite successfully attacks a host in the natural environment, the criterion of success being the development of the parasite progeny to maturity, the species attacked is described as a "natural host." Parasites are used in biological control work with respect to their natural hosts. However, when the mass breeding of parasites for field distribution has to be carried out, the provision of natural hosts in sufficient quantity is in many cases difficult or impossible, unless they can be easily obtained in large numbers from the field. But some of these hosts have only a single generation a year. Others live in the larval stage in parts of growing plants which cannot be satisfactorily handled so as to produce mass infestations; on the other hand, attempts to rear such insects on detached fragments of plant tissue often result in heavy mortality. Other hosts which are very satisfactory for parasite propagation in some respects, become very susceptible to epidemics of disease when kept in large numbers in confinement. Even without these difficulties, the propagation in the laboratory of large numbers of natural hosts is often tedious and expensive.

However, it has been found that parasites will sometimes attack hosts on which they never develop in the field, but which are very suitable for mass breeding in the laboratory. The method of breeding insect parasites on "unnatural hosts" has thus become an important phase of biological control work. The present paper is devoted to a discussion of this method.

There is a very large number of examples in the literature of the rearing of parasites on unnatural hosts, and no attempt will be made to survey all of them. A few of the outstanding cases may be cited to indicate the success with which this method has been used. Perhaps the best known case is that of the mass breeding of several species of *Trichogramma* on the eggs of the Angoumois grain moth, *Sitotroga cerealella*, Oliv., for liberation against *Diatraea saccharalis*, F., *Cydia pomonella*, L., and *Grapholitha molesta*, Busck. This has been done on a huge scale, and there are numerous reports on the techniques used for breeding both the host and parasite, and also on the measures of success obtained, *e.g.*, Flanders (1929), etc., Tucker (1936), Schread & Garman (1933). The subject in general has been mentioned by Clausen (1939).

The eggs of the Mediterranean flour moth, *Ephestia kühniella*, Zell., have been extensively used by Bradley (1941) as hosts in the propagation of *Chelonus annulipes*, Wesm., using a technique based on that of Noble & Hunt (1937) for rearing *Chelonus blackburni*, Cam. The former parasite is a species imported into America from Europe where it is a parasite of the European corn-borer, *Pyrausta nubilalis*, Hb. The same technique was used by the present writer in breeding large numbers of *Chelonus texanus*, Cress., a parasite of *Loxostege sticticalis*, L., for shipment to South Africa (see below).

Races of the Braconid, *Ascogaster quadridentatus*, Wesm., which normally attack *Cydia pomonella*, L., and *Laspeyresia nigricana*, Steph., in the field, have been propagated successfully in the laboratory on the oriental fruit moth, *Grapholitha molesta*, Busck. Recently, laboratory propagation of *Macrocentrus ancylivorus*, Rohw., for release against *G. molesta* in California, has been carried out using the potato tuber moth, *Gnorimoschema operculella*, Zell., as an unnatural host. Mention may also be made of the rearing of *Exeristes roborator*, F., on larvae of the ant, *Camponotus* (Thompson & Parker (1928)).

Numerous experimental examples using *Trichogramma evanescens*, Westw., and a general discussion of host suitability have been given by Salt (1938), where he analyses various factors which render a possible host unsuitable for attack by *Trichogramma* or for the subsequent development of the parasite larvae. These factors include physical resistance to attack offered by the chorion of the egg, quantity and fluidity of the host egg contents, etc. Here no attempt will be made to investigate the characters rendering a host suitable or otherwise for a particular parasite species ; only the practical importance of the use of unnatural hosts in breeding work will be considered.

Methods of utilisation of unnatural hosts may conveniently be divided into two separate categories. The first is that in which the unnatural hosts are attacked by the ovipositing female parasites, and eggs are laid, subsequent development occurring as with the natural host. The second major division comprises those examples in which, though the ovipositing female parasite will not oviposit on or in the unnatural hosts, the subsequent development of the parasite progeny will take place if parasite eggs are transferred artificially to suitable stages.

This division corresponds to the distinction made by Salt between the characters of a host rendering it suitable or otherwise to attack by the parasite, and those rendering it suitable for development of the parasite larvae, even though it may be unsuitable for attack by the ovipositing parasite.

There is every gradation between cases in which unnatural hosts are readily attacked and subsequent development of the parasite progeny is normal, to cases where no attack on the unnatural hosts is made, and no development occurs when parasite eggs are artificially transplanted to them. The whole series may be summarised as follows :—

Result of exposing " unnatural hosts " to attack by parasites, or transferring parasite eggs to " unnatural hosts " in suitable stages.

I. Attack readily.
II. Attack reluctantly or with difficulty.
III. No attack.
IV. No attack, but progeny transferred to " unnatural hosts."

a. Subsequent development normal.
b. Subsequent development sub-normal, *i.e.*, high mortality or abnormal progeny.
c. No progeny.

Obviously different parasites will react differently with single host species and *vice versa*, and the suitability of any one parasite/host relationship usually gives very little indication as to what will occur with other species.

A special case of IV occurring in the field is that of certain TACHINIDAE (*e.g.*, *Gonia*, *Rhacodineura*) and TRIGONALIDAE, which lay their eggs on the food plant of the host. These eggs may then be ingested by the host larva as it feeds, when they hatch in the larval intestine, subsequent development taking place at the expense of the host as with other types. Here the only provision made for her offspring by the ovipositing female parasite is the selection of sites for laying her eggs on a suitable host plant near to the correct host larvae. In these cases the progeny usually enters the natural host. It is possible, however, for the eggs to be ingested by unnatural hosts ; Thompson (1913) has used *Clisiocampa* larvae in this way as hosts for *Sturmia scutellata*, R.-D.

The mass breeding of *Trichogramma* on *Sitotroga* eggs and the breeding of species of *Chelonus* on those of *Ephestia* are examples of Group Ia, the most suitable type for laboratory breeding.

As examples of Groups I b and c may be cited the case of *Coccophagus gurneyi*, Comp., attacking species of *Pseudococcus*. On *P. longispinus*, Targ., development is sub-normal, and on *P. citri*, Risso, and *P. maritimus*, Ehrh., no development occurs. Another example of Group I c is that of *Melittobia acasta*, Wlk., on *Osmia rufa*, Panz., where ready attack occurs, but the host is unsuitable for the development of progeny. Salt (1938), in the paper mentioned above, gives the results of experiments on the suitability of various eggs as hosts for *Trichogramma*. For instance, *Trichogramma* attacked the eggs of *Bruchus obtectus*, Say, "though not with avidity," but only 1·5 per cent. of the eggs attacked produced progeny—a case that goes into Group II b. With the eggs of *Tenebrio molitor*, L., there was ready attack by the parasite but no progeny developed, a case of Group I c. It is unnecessary to give further examples of this, though very many exist, and we may now consider the examples that have occurred in the laboratory in the course of attempts at mass rearing of several parasite species.

2. Results obtained in the Laboratory 1941–1943.

(*a*). *Parasites of* CYDIA POMONELLA, L.

Whilst breeding parasites of *Cydia pomonella* for shipment for biological control purposes, a number of attempts were made to breed and rear parasites on unnatural hosts. *Ascogaster carpocapsae*, Vier., was offered the eggs of *Ephestia kühniella* but no attack occurred (Group III). Ovipositing females of *Cryptus sexannulatus*, Grav., *Ephialtes caudatus*, Ratz., and *Aenoplex carpocapsae*, Cush., were placed with cocoons of *Ephestia* but no attack took place. All these three species lay their eggs on the hibernating larvae of *Cydia* within their cocoons after stinging and paralysing the larvae. Development is ectoparasitic. If eggs laid in this way were transferred to larvae of *Ephestia* that had been killed by coddling for one minute at 100°F., and placed in small vials, subsequent development was regular, no excessive mortality occurring, and the resulting progeny were fertile and apparently normal (Group IV a).

These results are of importance in view of the extensive breeding work being carried out at present with codling moth parasites. With only a small number of *Cydia* larvae available, a large number of parasite eggs may be obtained by exposing a few *Cydia* cocoons to ovipositing parasites until superparasitism is heavy, and then transferring these eggs singly to coddled *Ephestia* larvae as described. In this way propagation of the parasites may be continued when supplies of *Cydia* larvae are limited, or when the prevalence of disease in field-collected material necessitates the expensive project of breeding host material in the laboratory, since breeding sufficient quantities of *Ephestia* larvae for rearing is comparatively inexpensive.

(*b*). *Parasites of* LOXOSTEGE STICTICALIS, L.

As mentioned above, *Chelonus texanus*, Cress., a parasite of the sugar-beet webworm, was bred in large numbers on *Ephestia kühniella*. This species was obtained from *Loxostege* material from Montana. Females readily attacked *Loxostege* eggs, but much material was lost through a disease which attacked fully grown larvae of the host, and which antiseptic methods failed to prevent. Following the technique used for *Chelonus annulipes*, eggs of *Ephestia* were exposed to ovipositing females of *C. texanus*. The females attacked the eggs readily, and subsequent development of host and parasite was normal. Four generations were raised, and 300,000 parasitised hosts shipped to South Africa, giving a very successful example of the breeding of parasite material on an unnatural host (Group Ia).

Two examples belonging to Group Ib may be mentioned. *Meteorus loxostegei*, Vier., a parasite of *Loxostege*, was reared from field material and was successfully bred in the laboratory on *Loxostege*, which it attacks in the young larval stage, laying its egg within the host, which is not killed by the development of the initial stages of the parasite. As with *C. texanus*, subsequent mortality of the host due to disease seriously interfered with mass breeding. Hence, ovipositing *Meteorus* females were offered larvae of both *Cydia pomonella* and *Ephestia kühniella*. In the case of *Cydia*, the larvae were full grown hibernating larvae taken from their cocoons, and in that of *Ephestia* larvae of different sizes. In both cases larvae were readily attacked, and subsequent dissection showed that eggs had been laid. However, development of the parasite was abnormal, and mortality was high, only one adult coming through from fifty of each host attacked. First-stage larvae were found in dissections, and presumably physiological unsuitability of the host prevented further development, though a few of the parasites developed as far as the full grown larval stage and then died. Hence the hosts could not have been completely unsuitable. The very high mortality shows that these examples belong to the lower limit of Group Ib.

(*c*). *Parasites of* OSCINELLA FRIT, L.

A further very successful example of the use of unnatural hosts, investigated in 1942, was that involving the breeding of *Spalangia drosophilae*, Ashm., a parasite obtained during investigations of the North America parasites of the frit fly, carried out with a view to obtaining suitable parasite species for introduction into England as biological control agents against this pest. Of the parasites obtained *Spalangia* appeared to be the most promising for introduction. However, the problem of obtaining large numbers for shipment and liberation was difficult, since it was found impossible for practical purposes to breed large numbers of *Oscinella* puparia —the host of *Spalangia*—and an expensive procedure to obtain sufficient parasite material in the field, since this entailed minute dissection of a huge quantity of wheat plants infested with parasitised frit material. Hence an approach through unnatural hosts was sought. The host list for *S. drosophilae* given in the Parasite Catalogue of the Imperial Parasite Service consists of :—

Alysia ridibunda, Say (Braconidae).

Lyperosia irritans, L. (Muscidae).

Psilodora rufocincta, Kieffer (Cynipoidea).

Theresia claripalpis, Wulp (Tachinidae).

Ashmead (1894) states that " the type was reared by me from a Dipterous larva of *Drosophila* sp.," and it seems apparent that Dipterous puparia and Hymenopterous cocoons are the preferred hosts. Puparia of *Musca domestica*, L., were offered to ovipositing female parasites, but although some attacks took place only a single individual offspring was obtained, and mortality was very high (Group IIb). The chitinous puparium of *Musca* seemed to be too thick for easy penetration by the ovipositor, and the contained pupa was not, in many cases, paralysed to arrest development. It seemed that a smaller, less heavily chitinised puparium was required, and puparia of *Drosophila melanogaster*, Mg., were tried. This experiment proved to be a complete success, the puparia were very readily attacked, eggs laid—with a strong avoidance of superparasitism—and the mortality in the immature stages was very low, under 3 per cent. The progeny were healthy, and a stock has been reared on *Drosophila* puparia for six generations. Owing to the ease with which this host can be bred in the laboratory, it provides a method of breeding *Spalangia* by which large numbers of the parasites for liberation can be produced at very low cost.

This example is, of course, a good example of Group I a, though it is difficult in this case to be sure that *Drosophila* is not a natural, rather than an unnatural, host.

Other frit fly parasites were tried with *Drosophila* as host. *Loxotropa* sp. attacked puparia, but not readily, and a few individuals were reared through (Group II a). *Hexacola* and *Polyscelis*, larval parasites of frit, were offered *Drosophila* larvae under many different conditions—in wheat stems, in muslin and filter paper soaked in an infusion of wheat plants, etc., but no progeny was reared. *Hexacola* did, in a few cases, apparently attack the *Drosophila* larvae, but no eggs were found on dissection.

3. Artificial Rearing of Parasites.

The foregoing examples of mass breeding of parasites for biological control purposes using unnatural hosts suggests the possibility of devising purely artificial nutritive media on which parasite larvae could be reared to maturity. If this could be done, it might be of great practical importance, facilitating the raising of large numbers of parasites with comparatively few hosts required for obtaining parasite eggs for transference to the media. Moreover, the composition of such media might shed light on the exact relationships between parasite larva and host in respect to chemical suitability.

A number of species of Tachinids and Chalcids, whose larvae enter into anatomical relationships with their hosts, would seem to be wholly unsuited for this type of propagation, but there appears to be no *a priori* reason why it should not be successful with other types of parasite larvae.

The use of artificial food media for adult leaf-hoppers and Aphids has been successfully tried in experiments on virus diseases (Carter (1927), Hamilton (1930)), but no actual rearing of insects occurred here. Hawkes (1920) working with *Adalia bipunctata*, Muls., an aphid-feeding species of Coccinellid, fed the adults successfully on pounded dates. It was found to be impossible to feed the newly hatched larvae in this way, but one larva was reared from the second stage to the adult on dates alone. Most of the older larvae could be kept alive on this food, but did not grow much. Shannon (1923) reared *Sarcophaga cimbicis*, Tns., and *S. sarracenioides*, Aldr., on a beef infusion in agar, several generations being produced. It is possible in this instance that the larvae are mycetophagous, feeding on yeast cells and fungus growth, and not on the actual medium.

The rearing of *Drosophila* spp. in the laboratory on artificial media is too well known to warrant discussion here. Michelbacher, Hoskins & Herms (1932) have also developed a synthetic medium for studying nutritional requirements of Dipterous larvae. Eyer (1921) reared onion fly on an agar medium with an infusion of onion and cabbage. The example of the rearing of Sarcophagids given above might prove to be adaptable for the rearing of parasitic species of the same group.

So far as the writer is aware, there is no reference in the literature to the rearing of endoparasitic larvae in artificial media, and it seemed probable that it might be more feasible to rear ectoparasitic larvae on a gelatinised nutritive medium, or on a liquid medium through a membrane. It was felt that the respiratory requirements of an endoparasitic larva might be difficult to meet, whereas there would be no difficulty with an ectoparasitic species in this regard. For this purpose ectoparasites of cocoons of *Cydia pomonella*, L., *Ephialtes caudatus*, Ratz., and *Cryptus sexannulatus*, Grav., were tried. Eggs were placed on nutritive gelatine slopes, and also on raw beef. The eggs hatched, and the first-stage larvae increased in size. Only in one instance, however, did moulting take place, with a larva feeding on raw beef. None was reared through to the adult.

4. Discussion.

As has been indicated above, the propagation of parasites on unnatural hosts and the possibilities of the use of artificial media are of great practical importance in the breeding of parasites in biological control work. There is, however, one objection that is often raised in connection with such breeding. Does laboratory breeding on unnatural hosts, especially if this is continued for several generations, affect the host preferences of the ovipositing parasites ? In other words, when parasites are bred in such a way, will they still be capable of attacking their natural hosts in the field, or will they now only attack the species of host from which they were bred ? Much has been written on this subject, not only in connection with host selection by parasite species, but also in connection with phytophagous species.

Hopkins (1917) stated that " an insect which breeds on two or more hosts will continue to breed on the host to which it has become adapted," a statement similar to Walsh's " Host Selection Principle " postulated in 1864.

This certainly applies to many cases in which there are definite biological races of the same species which feed on different hosts. Thus Woods (1915) found two races of *Rhagoletis pomonella*, Walsh, one on apple, the other on blueberry and huckleberry, which would not lay or feed on the food-plant of the other race. More recently Hall (1943) has found a third race restricted to dogwood (*Cornus amomum*). Similar behaviour was found by Thorpe (1929 & 1931) with two races of *Hyponomeuta padellus*, L., one on apple, the other on hawthorn and blackthorn. Craighead (1921), using a number of species of polyphagous Cerambycids, induced experimentally races which showed decided preferences to lay on the same wood from which they themselves had been reared. This subject of biological races has been fully reviewed by Thorpe (1930).

Of greater interest in the present connection are those cases where it is claimed that races with different host preferences have been formed in the laboratory. Here might be cited the work of Sikora (1917), Bacot (1917), Nuttall (1919) and Keilin & Nuttall (1919) on the races of *Pediculus humanus*, L., in which the race *capitis* has been changed into the race *corporis* having different habits. Schröder (1903) altered the oviposition preference of adult *Phratora vitellinae*, L., in the laboratory from 9 per cent. to 42 per cent. for the downy leaves of *Salix viminalis* when offered these and the normal host, the smooth-leaved *S. fragilis*, after forcing *Phratora* larvae to feed on *S. viminalis* for four generations. Pictet (1911) produced a race of *Lasiocampa quercus*, L., the larvae of which showed a preference for pine needles rather than flat leaves, and could only be made to return to their original host with difficulty.

Perhaps the most striking of such experiments are those of Harrison (1927) on *Pontania salicis*, Christ, which is a gall-forming species of sawfly attacking willows. He altered the host preferences of one of the naturally occurring biological races from *Salix andersoniana* to *S. rubra* in the course of four years, at the end of which time all preference for the original host was lost. There are also examples involving entomophagous insects. Marchal (1927) found two naturally occurring races of *Trichogramma*, one attacking the eggs of *Archips rosana*, L., the other refusing to do so, and there were also other biological differences between them. In the laboratory several attempts have been made to change parasite host preferences. Hase (1929) bred *Trichogramma evanescens*, Westw., on *Ephestia* and *Galleria* eggs for three years without changing the females' host preference. Salt (1935), using Hase's stock, raised 63 generations on *Sitotroga* eggs and 43 on those of *Ephestia*. After this time both strains still showed a preference for eggs of *Ephestia*, but " the preference for eggs of *Ephestia* shown by the strain reared on *Sitotroga* was less than that shown by the strain reared on *Ephestia*." This difference, however, was not great. Salt (1938) also found that no strain of *Trichogramma* suitable for eggs of *Bruchus* could be built up. Thorpe & Jones (1937), in experiments on olfactory conditioning in the Ichneumonid, *Nemeritis canescens*, Grav., towards two different hosts, bred the parasite on *Ephestia* and *Meliphora*. It was found that individuals bred from *Meliphora* had their preference for the smell of *Ephestia* reduced from 85 per cent. to 65·8 per cent. when there was a choice between both hosts. However, continuous rearing on *Meliphora* did not alter this preference, and no " race " having a strong preference for *Meliphora* was produced. This work is interesting in that it does show a definite effect of the larval environment on the reactions of the adult.

It is worth noting here the experiments of Thompson & Parker (1928) on the host selection of two naturally occurring strains of *Pyrausta nubilalis*, Hb., one from maize, the other from *Artemisia*. They found that both strains showed a decided preference for laying on maize, but that the *Artemisia* strain showed a slight attraction to that food plant which was lacking in the maize-reared strain. Thus no rigid preference had developed even after long isolation in the field on a second food plant.

During work on the parasites of the codling moth, the present writer bred *Dibrachys cavus*, Wlk., on both larvae and pupae of *Cydia*; in the former case the parasite was ectoparasitic, in the latter, endoparasitic. The parasites had a definite preference for the larvae. After breeding a strain on pupae for several generations this preference did not change. Also, in connection with the breeding of *Chelonus annulipes* and *C. texanus* on *Ephestia* eggs in the laboratory, there has been no suggestion that their capabilities for attacking the natural hosts in the field have been in any way impaired.

It would seem, then, that it is possible to alter the host preferences of insect species in the laboratory by forcing them to accept for oviposition different food materials on which their offspring will be nourished. Usually there is, however, a very heavy initial mortality when this occurs. This would point to the continued propagation of only a special fraction of the individuals involved, a fraction which might have some genetical peculiarities making it adaptable to the second host, and which might in some way alter its host preferences.

This would not be a case of altering the host preferences of an entire population, but merely selecting a strain out of that population which showed adaptability to, and possible preference for, the new host, and then accentuating this preference by continued selective mating. This will not account for all such cases, and the occurrence of " Dauermodifikationen " (temporary and reversible alterations of the hereditary constitution) has also been postulated in certain instances, on the assumption that the cytoplasm of the insect is affected by the change over of host, that this alteration changes the individual's reaction to the new host, and that this may be transmitted to offspring by cytoplasmic inheritance. Such modifications have been found to be less fixed than those of genetical origin.

In connection with the successful laboratory rearing of parasites on unnatural hosts, it will be noted that there does not occur the heavy initial mortality seen in many of the examples of induced change of host preference given above. Thus there is no apparent segregation of a strain particularly adapted to the unnatural host, and it would appear that the possibilities of such breeding interfering with the success of the introduction of a parasite species is remote.

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EQUIPMENT AND METHOD EMPLOYED IN BREEDING *AËDES AEGYPTI*, L., FOR THE BIOLOGICAL ASSAY OF INSECTICIDES.

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Introduction.

During the course of the war, the consumption of so-called fly sprays for mosquito control operations has increased enormously. Since the essential toxic ingredients were in short supply, it became necessary to determine the minimum concentrations likely to be satisfactory in practice, and to evolve new combinations of toxic principles. The information was required urgently, and *Aëdes aegypti* was chosen as the test insect because it was known to be much easier to rear in large numbers than almost any other species of mosquito. At the time this advantage was thought to outweigh the disadvantage of using a non vector of malaria.

Equipment.

In order to produce insects of reasonably standard resistance to insecticides, it is necessary to breed them under controlled conditions. The first requirement is a constant temperature and humidity room. The simple unit type of equipment which has been developed controls the temperature at 28°C. ±1°C. and the humidity at 70 per cent. R.H. ±2 per cent. in a room $5 \times 5 \times 7$ ft. high. It consists of a fan constantly in operation, the temperature control apparatus, and the humidity control apparatus. The fan, hair-hygrometer with electrical contacts, the mercury-toluene regulator, the water bath and the air heater are all mounted on a board 3 ft. × 1 ft. Each unit may be described briefly as follows :—

The air-circulating fan.

Any fan which can be adjusted to give a gentle circulation of air first over the hair-hygrometer and mercury-toluene regulator, then over the humidifying bath and air heater, and to some extent in the room, can be employed. A table fan set to one of the slower speeds, or the light plastic type of window fan is satisfactory. The fan is allowed to run constantly.

The temperature control unit.

The thermostat employed was a mercury-toluene regulator of the standard type coupled with 1 k.w. fire element through a " Sunvic " vacuum control switch.

The humidity control unit.

The humidity was controlled by a hair-hygrometer with electrical contacts made in a mercury cup. The hair-hygrometer operated the immersion heater in a small water bath through the intermediary of a " Sunvic " control. Since a supply of water for the bath could not conveniently be arranged from the mains, a constant level feed of distilled water from an aspirator was employed. As the water level falls, the lower end of an inlet tube is exposed, and entry of air into the aspirator by this means allows more water to run into the bath through another tube which dips more deeply into the bath. In order to guard against accidental failure of this supply, a mercury tumbler switch was supported on a lever which was controlled by a float on the water bath ; when the level of water fell by more than a certain amount, the immersion heater was cut off and so prevented from burning out by overheating.

This improvised apparatus has given trouble-free service over a period of twelve months with only very infrequent cleaning. The performance is constantly checked by a thermohygrograph.

Method of Rearing.

Leeson (1932) has described a method for rearing *Aëdes aegypti* which is convenient for maintaining a stock from which only comparatively small numbers of insects are being taken. For insecticidal work, however, where thousands of insects are required, the breeding method must be put on a more mass-production basis. Fortunately it has been shown (Macgregor, 1929) that breadcrumbs provide a very suitable larval food. It appears that the larvae eat both the breadcrumbs themselves and also organisms in the resulting infusion. After an initial period of experimentation, the following procedure, which yields large numbers of good-sized active adults, has been adopted.

The eggs.

The eggs are obtained from three cages of adults, maintained in the constant temperature room, one of which is fed to repletion on the arm of the operator each day in rotation (Roy, 1936). Each cage contains about one hundred females and a varying number of males. The stock is replenished from time to time with males and females as seems necessary. Petri dishes of tap water, placed on a black circle painted on the otherwise cream floor of the cage, are provided for oviposition (Buxton, 1927). The females oviposit about three days after their blood meal and should be fed again on this day. On each occasion about twenty eggs are laid by an individual (Buxton, 1927). Each day the eggs from the three cages are collected in a large Buchner filter funnel on a dated paper. The breeding insects are not provided with an alternative food supply since this reduces the eagerness of the females for blood. This means that the males die off relatively quickly but the females continue to produce fertile eggs for some time after copulation. The eggs are stored for four days or more, on damp filter paper in a jar in the constant temperature room before use. This is advisable since when placed in water the eggs then hatch over a comparatively short period (Buxton, 1927).

The larvae.

The breadcrumbs, which supply the larval food directly or indirectly, can be sprinkled on to the larval bowls dry but it is much better to prepare an infusion. The recommended infusion is made up as follows. Brown bread is sliced, dried and crumbled—the latter operation can be accomplished by rolling but it is much quicker to use a mincing machine. To a 2-litre winchester bottle containing 2,000 cc. of tap water and 10 cc. of 10 per cent. sodium chloride solution, 30 gms. of breadcrumbs measured volumetrically are added. The mixture is shaken and stored for five days at 20°C.±2°C. On each day the bottles should be shaken. It has been found that a longer period of storage than five days, or storage at higher temperatures, leads to the production of a toxic medium due to yeast fermentation which is favoured by higher temperatures. Before being fed to the larvae the infusion is strained through voile, warmed, and aerated. In order that the medium fed to the different bowls may be as uniform as possible it is advisable to mix the contents of several bottles in a larger container and to air the whole together by blowing or sucking air through it whilst it stands in a bath of warm water. The temperature can also be brought to 28°C. by using hot water for dilution when necessary (*cf.* below).

A fresh culture is started and treated in the following manner :—

First day.	Place the four-day-old eggs on the paper in 1,000 cc. of a medium consisting of 20–30 per cent. of the infusion in cold tap water. The shock of the cold water together with the presence of the infusion stimulates hatching (Atkin & Bacot, 1917 ; Buxton, 1927).

Second day.	Add 200 cc. warmed undiluted infusion to the bowl and remove the filter paper.
Third day.	Completely change the medium by pouring off through a voile strainer and divide the culture so that there are about 1,000 larvae per 1,000 cc. of medium, using 40–50 per cent. of the infusion in tap water. The division of the larvae can be most easily effected by pipetting them into a graduated tube with a bulb teat pipette. The bottom of the graduated tube should be covered with voile so that the water can drain out. The approximate volume of a thousand drained larvae can be determined by one or two countings (at this stage about 0·3 cc.=1,000 larvae).
Fourth day.	Completely change the medium to 60–70 per cent. infusion.
Fifth day.	Completely change the medium to 80 per cent. infusion.
Sixth day.	The first pupae should be present. In any case if the larvae are in the last instar change to 100 per cent. infusion.
Seventh day.	Adjust the amount of infusion according to the number of larvae still feeding. (The pupae do not feed.)
Subsequent days.	After the seventh day, when emergence begins, the larval bowls are placed in storage cages for three days. During this time the water is changed and a little fresh infusion is added if required. An excess of infusion results in the drowning of the emerging adults or the formation of a scum.

If on the fourth or fifth day the medium is completely cleared when it is due for renewal, this is either because there are too many larvae per bowl or because the medium used on previous days has failed to mature properly. The remedy lies in giving a larger volume of infusion and not in increasing the concentration beyond that recommended. In this way injurious effects associated with too strong a medium can be avoided.

The adults.

At the end of the third day in the cage, the larval bowls are removed and the insects are sprayed on the following day when they are one to four days old, since they are then at their maximum resistance. During the period of emergence and until they are sprayed, the insects are supplied with a dish of lump sugar and raisins and a pot of wet cotton wool. In the absence of blood the females as well as the males live on this diet. The insects used in the insecticidal tests are of course not blood fed. The sugar or raisin fed females are somewhat more susceptible to sprays than blood fed individuals of the same age (David & Bracey, unpublished).

Summary.

A method of rearing large numbers of *Aëdes aegypti* for the biological assay of insecticides is described. The larval food found to be most satisfactory was a breadcrumb infusion. Blood is necessary for oviposition (human blood is best), but the main batches of insects destined for spraying are fed on water, sugar and raisins.

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CONTROL OF HEAD AND PUBIC LICE.

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The lice that infect man may be one or more of the three species, *Pediculus humanus capitis, P. h. corporis* or *Phthirus pubis*, and this paper deals with treatments for the first and last of these.

A good pediculicide should possess certain important features : (1) it should act quickly ; (2) its effect should be pronounced on both the adult and the nit ; (3) a single application should cure the infestation ; (4) its protective power should last for at least 24 hours in order to allow sufficient time for carrying out delousing measures in the patient's family or in his environment ; (5) it should be possible to carry out the treatment in both the head and the pubic regions ; (6) the presence of ulcerous or eczematous conditions should not be regarded as contra-indicating treatment ; (7) the operation should be such as can be performed with ease by technical or non-technical personnel, and (8) the treatment should be inexpensive.

A large number of remedies have been suggested from time to time and, though some of them are still being used, it is now a settled fact that none of them is satisfactory. While they may perhaps kill the adult louse, they fail to reach the strongly protected nits. They are, moreover, uncertain in their action and often cause considerable local irritation.

Head Lice.

Attention has recently been focussed on two pediculicides, lauryl thiocyanate and lethane 384 special, which is also a thiocyanate compound ; the specifications of these two preparations have been given by Busvine & Buxton (1942). These authors have pointed out that when they are used in strengths of 25 per cent. and 50 per cent., respectively, the failure rate as indicated by the presence of living lice or unaffected eggs immediately at the end of the treatment varies from 1·8 to 7·8 in the case of lauryl thiocyanate and from 7·8 to 15·4 with lethane. These authors, however, report that the failure on those going into a clean environment is under 2 per cent. and always under 10 per cent. Other remedies that have been recommended by these authors are derris cream made up in 1 per cent. rotenone strength. They, however, admit that in 25 per cent. concentration (the strength suggested by them as very effective), thiocyanate preparations cannot be regarded as safe, though no ill effects have occurred among the large number of patients who have been treated in the above way. They have also pointed out that neither derris nor thiocyanate can be applied on the scrotal region of the body. A necessary part of the treatment for the effective destruction of the adult and the nit is that the head should not be washed for 7 to 10 days after treatment with any of the remedies specified above. The Ministry of Health (1943) has now published a memorandum on the use of thiocyanate for controlling head lice. No directions have, however, been given on the advisability of the use of these preparations on ulcerated skin. Gamlin (1943), on the other hand, questions the effectiveness of thiocyanates on nits and suggests the soaking of the hair with 2 per cent. hot lysol before lethane is applied.

In our experience pyrethrum has proved extremely satisfactory and, although we have had no opportunity of evaluating the comparative merits of pyrethrum and the thiocyanate compounds already mentioned, we are of the opinion that the former fulfils all the conditions enumerated above, and is in many ways an ideal pediculicide.

Thus it can be used not only on the scalp but also on the scrotum and the perineum. Even tender skins show no signs of irritation. It can also be safely employed in the hair even when extensive ulceration is present on the scalp.

Pyrethrin and other active constituents of pyrethrum (Roy & Ghosh, 1942 *a*) are easily dissolved in kerosene and, when used in this form, pyrethrum quickly paralyses the activities of the louse. It also acts on the nit as quickly and effectively as on the adult. It has already been pointed out that kerosene alone is incapable of reaching the ovum through the openings in the operculum, whereas a mixture of kerosene and pyrethrum quickly does so (Roy & Ghosh, 1942 *b*). If, on the other hand, the patients have to return to their previous unhealthy surroundings, the insecticide must then be allowed to remain on the head for 24 hours after treatment. This interval may be profitably utilised for treating infested individuals living in the environment where the infestation was acquired. It has also been noticed that under such conditions re-infestation of the head within 24 hours after treatment cannot take place from the patient's personal bedding, clothing etc. Any louse that has migrated to these situations will die within 24 hours, as in nature it cannot establish itself on the hairs of other parts of the body except the head (Roy & Ghosh, 1944 *a*). (Findings in the laboratory are, of course, different.)

Our method of treatment for dealing with infestation by the head louse is as follows :—Every part of the hair from the root to the tip should be sprayed by means of a d'Vilbiss atomiser No. 15 or 16, with a mixture of pyrethrum extract and kerosene. A concentrated mixture suitably diluted to contain 0·12 mg. percentage pyrethrins has been used in all our cases. We have recently started experiments to determine the minimum amount of pyrethrins I and II in a mixture to be effective against the head louse. The household insecticide, prepared by soaking pyrethrum powder of known pyrethrin strength in kerosene, is also being investigated. A towel is generally held over the face in order to protect the eyes, though we repeat that pyrethrum itself is non-irritating to the eyes (Roy, Ghosh & Chopra, 1941). The insecticide is rubbed in the hair in order to ensure uniform distribution of the oil globules that have a tendency to accumulate on parts directly exposed to the spray.

It is not necessary to comb the hair in order forcibly to dislodge the adults and the nits after the insecticide has been applied. The essential requirement of the treatment is close contact between the insecticide and the louse or the nit, and when once this has been established, one can be fairly certain that the effect will be deadly on the louse and also on the nit. It is not necessary that the contact should be prolonged ; a mere touch will produce the desired results. When, however, it is intended to study the population of lice on such heads, the hair should be combed and all lice either dead or in a dying state collected and preserved in spirit. For those who are to return to clean surroundings, the hair may be washed with soap and water an hour or more after the treatment has been given. About 1 oz. of the diluted mixture will be required for the treatment of a female patient having hair reaching the waist.

We now present a complete report (*vide* Table I), including those previously published (Roy, Ghosh & Chopra, 1941 : Roy & Ghosh, 1942 *b* ; Roy & Ghosh, 1944 *a*), on the success attained in the treatment of infestation by the head louse with pyrethrum. The cases have been placed under two categories. In the first series, comprising 124 patients, the treatment was carried out in the hospital and at least a fortnight had elapsed before the patients were discharged. Just before discharge they were carefully examined, and in none of them was any louse or nit found. The other group included 85 cases who received the treatment in the out-patients' clinic. Over 50 per cent. of these patients were later followed up, and all of them remained free from lice for 10 to 15 days after treatment ; 30 per cent. who had returned to clean surroundings remained free for over three to six months. Only four patients returned for a second course of treatment within one month ; among them were two sisters. These were evidently cases of reinfestation, and in all of them there was a clear history of the infestation having been acquired in their environment. It is perhaps going rather far to reckon all those cases which did not return for a second course of this treatment as cured.

TABLE I.

Treatment of pediculosis of the head with pyrethrum extract spray.

Total Number	Age		Sex		Treatment carried out by		Results
	Maximum	Minimum	Male	Female	Technical personnel	Other personnel	
Hospital cases ... 124	62	2	27	97	64	60	Free from lice during further stay in the hospital for a period varying from a fortnight to over six months
Out-patients 85	55	5	4	81	11	74	Only 4 patients returned for a second course of treatment within one month

Phthirus pubis.

In all 19 cases have so far come to our notice. Among them were four cases in children, all below 12 years of age, in all of whom the infestation was confined to the eye-lashes. The symptoms were severe inflammation of the eye-lids, conjunctivitis and blepharitis. In one patient *P. pubis* were also found on the temple where one adult louse and two nits were discovered. Buxton (1941) had already reported its presence on the head. The rest of the cases were in adult males. In only one patient was the infestation venereal in origin. No case showed infestation on the back of the chest, lower extremity below the knee and on the beard. One patient had infestation confined to one arm and another to the chest only. The pubic and the perineal regions were affected in the rest.

Treatment.

Previous shaving of the affected parts was advised in all such cases. Involvement of the eye-lashes is now being treated with pyrethrum ointment prepared with vaseline 1 : 8 (Roy, Ghosh & Chopra, 1941). The adult louse and the larva are killed thereby, and the dead ones become dislodged within 24 hours; a correspondingly rapid improvement of the local conditions is also a noticeable feature. Pyrethrum when mixed with vaseline does not act on nits; this necessitates the continuation of the application for five nights in succession, *i.e.* till the last nit has hatched and the larva has escaped.

For infestation of the pubic, scrotal and anal regions, pyrethrum-kerosene spray has been found to be the ideal method of treatment, and it is done in the same way as for infested heads. The existence of ring-worm or eczema is not a contra-indication to this treatment.

Pyrethrum mixed with vaseline has also been used against the pubic louse by Twinn and Macnay (1943) who reported that the pyrethrum preparations caused little or no discomfort even when the skin infested by *P. pubis* had first been washed or scrubbed.

Discussion.

It will be noticed from the above that pyrethrum can be successfully employed for the treatment of infestation of the body by the head and the pubic lice. Not only the adult louse but also the nit is quickly affected and only one application will bring about the desired result. Though kerosene preparations are the cheapest, their rather unpleasant nature will limit their popularity, and in its place deodorised base oil will be preferred. A drop of oil geranium, neroli, citronella oil or lavender oil added to the mixture will give the latter a pleasant odour. The cost of the medicine including kerosene for the treatment of 80 female patients will not be more than two shillings calculated at the prevailing war-time prices in Calcutta. Deodorised base oil will be a little more costly.

Pyrethrum has also been used by Angevine (1941) for the treatment of pediculosis of the head. He used it as an ointment prepared with crystalline dimethyl methylene ether of allyl tetroxybenzene in vaseline. According to him, one application of this ointment, which kills lice in a few minutes and is toxic to their eggs, eliminated infestation in all of the 1,504 cases in which it was tested. We have pointed out elsewhere that the normal method of entry of the active constituents of pyrethrum is through the respiratory openings of the insect and not through the cuticle (Roy, Ghosh & Chopra, 1943 ; Roy & Ghosh, 1944 *b*). In these circumstances we are doubtful if the insect is affected by the external application of pyrethrum. In such cases the insect is asphyxiated rather than killed by the toxic effect of the insecticide. To what extent pyrethrum mixed with vaseline can reach the ovum when applied on the outer surface of the nit is extremely doubtful.

Subsequently Twinn & Macnay (1943) found that extracts of pyrethrum at various concentrations in deodorised oil killed head lice and their eggs.

The recent work of Potter and Tattersfield (1943) proves that pyrethrum is as toxic to the eggs of a considerable number of a species of insects as some recognised official synthetic products, lauryl thiocyanate, β-butoxy β′thiocyanodiethyl ether and 3, 5 dinitro-o-cresol. They further state that the pyrethrins are more toxic, weight for weight, than 3, 5 dinitro-o-cresol which is recognised as one of the most potent ovicides. It is possible that the pyrethrum powder from waste flowers and leaves which is also potent against insects (Symes, McMahon & Haddow, 1942), may be utilised for this treatment, and the cost per head will be still further reduced.

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PHYSIOLOGICAL AND ECOLOGICAL STUDIES ON THE SPECIES OF *CAPNODIS* IN PALESTINE (COL., BUPRESTIDAE).

I. STUDIES ON THE EGGS.

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Foreword.

Capnodis presents to the fruit grower in Palestine one of the most important pest problems. Like many other Buprestids, its larvae bore into the roots of the trees and often kill the entire tree within a short period. Trees may be attacked in the nursery and in the young grove, but the percentage of trees that succumb to attack becomes noticeable especially after the beginning of the fruit-bearing period.

There are diverse opinions as to the real economic importance of these insects. Certain entomologists claim them to be a secondary pest. Bodenheimer (1930) for instance, states that almond plantations in heavier soils are more infested than those in sandy soils because the heavy soil is less suitable to that tree ; also, that weak trees are more often attacked than stronger trees. Others, however, contend that plantations in sandy soil are less attacked for other reasons, namely, the difficulty that the larvae of *Capnodis* have in penetrating sandy soil.

Fruit growers, although they do not deny any of the facts, and do not oppose Bodenheimer's view, maintain that the weakness of the tree, whereby the tree is rendered susceptible to attack by *Capnodis*, begins somewhat too early, namely simultaneously with the fruit-bearing period, and that therefore the pest is of primary importance.

Be that as it may, these pests cause considerable worry to the fruit grower, and many questions regarding them have been raised. Among the problems arising are : (1) the possibilities of the selection of resistant root stock ; (2) problems of irrigation ; (3) selection of proper site and soils for groves, etc. In addition, there are many questions connected with control practices.

" Worming " of the roots was and still is in many places a common practice. It is usually carried out in spring and autumn. The collection of the adults from the trees is a measure in which children are especially engaged. For two or three years, attempts were made to control the larvae by means of fumigants, such as ethylene chloride, but these were found to injure the trees. The practice, recommended by some European entomologists, of spraying of the trees with stomach poisons against the adults has been introduced with some measure of success. The correct period when these measures should be carried out as well as other ecological and physiological questions remain to be solved, and in an endeavour to find the reply to some of these questions, the work, the results of which are here recorded, was undertaken some seven years ago.

Introduction.

There are six species of *Capnodis* in Palestine. The economic status of each depends primarily upon its distribution, the importance of its food plant, and the extent of the cultivation of its host in the particular area of its distribution. Thus *Capnodis tenebricosa*, Ol., the smallest of the species, is of little economic importance. Although it is apparently distributed throughout the country, it is rare ; adults of this species were found once in Benyamina on *Rumex* sp. (Bodenheimer, June 1926), and once in Wadi Fara, near Jericho, on *Zizyphus spina-christi* (Bitynsky-Salz, June 1942). *C. miliaris*, Klug, the largest of the species, whose host is *Populus*, is also at present of very little importance, though in view of the introduction of poplar plantations in the Huleh district, it may become a serious pest. *C. cariosa*, Pall., lives on *Pistacia* spp. and pepper, *Schinus molle*. It is especially abundant on the hills of Samaria and Galilee, but also occurs in other parts of the country. *C. porosa*, Klug, attacks almonds in the Judean and Samarian hills. It occurs in the area from Shefa Amar to Hebron but not in the coastal plain, nor in the other valleys. For this reason its economic status is of less importance than that of the two other species, the hosts of which are identical, *viz.*, *C. carbonaria*, Klug, and *C. tenebrionis*, L. Both of these attack all stone fruit trees and are considered major pests of them. *C. tenebrionis* is found in the mountainous regions and in the inland valleys, but is not found in the coastal plain from Benyamina and southwards. *C. carbonaria* is abundant throughout the country, and from this point of view it is the most troublesome, although when found together with *C. tenebrionis* the latter is the more serious.

The following is a list of the species occurring in Palestine, with their hosts and economic status :—

Species	Host	Economic Importance
Capnodis miliaris	*Populus*	None
Capnodis cariosa	*Pistacia* spp., *Schinus molle*	Slight
Capnodis porosa	*Prunus* spp.	Slight
Capnodis carbonaria	*Prunus* spp.	Severe
Capnodis tenebrionis	*Prunus* spp.	Severe
Capnodis tenebricosa	*Rumex*	None

The present study was carried out on *C. carbonaria*, *C. tenebrionis* and to a less extent on *C. cariosa*.

Size and Shape of the Eggs.

The eggs of *Capnodis* are white. When freely laid, they are oval in shape, very much like a hen's egg ; when deposited in crevices or on an uneven surface, they may assume an angular shape or become flat and compressed, depending upon the surface on which they are deposited.

In size the eggs of the various species vary as follows : the largest are those of *C. tenebrionis* and *C. miliaris*. They may reach a length of 1·5 mm. and a width of 1·2 mm. Those of *C. carbonaria* are smaller, while the eggs of *C. cariosa* are the smallest. These may reach a length of 1·2 mm. and a width of 1 mm. The eggs of *C. porosa* and *C. tenebricosa* are unknown to the writer.

The proportion in the size of the eggs of the various species is rather peculiar since *C. cariosa*, which lays the smallest eggs, is, next to *C. miliaris*, the largest of the species, while *C. tenebrionis*, which lays the largest eggs, is, next to *C. tenebricosa*, the smallest of the *Capnodis* species in Palestine. Each egg of *C. tenebrionis* weighs about 0·632 mg.

Composition of the Egg Shell.

Examination of the eggs under the binocular microscope reveals the fact that the white colour of the eggs is due to a thin shell that easily crumbles, covering the translucent cream-coloured egg membrane. A careful microchemical analysis, carried out by Dr. Paul Haas, was made of *C. tenebrionis* eggs in order to identify the substance of which the egg shell is composed, with the following results :—

Cations :	Potassium	+	Anions :	Urates	—
	Calcium	++		Phosphate	—
	Magnesium	++		Sulphate	—
	Sodium	—		Oxalate	—
				Chloride	+
				Carbonate	+

Effects of Relative Humidity.

The chemical composition of the egg shell seems to play an important rôle in protecting the egg from the ill effects of too low relative humidity. Experiments on eggs at various degrees of relative humidity were carried out in order to establish their effect. In these the eggs were placed in very small glass tubes, one opening being plugged with loose cotton, and the other end being closed with perforated tin foil. These were then hung in a large test tube over the substance controlling the relative humidity. The tube containing the eggs was partially open and very near the salt solution. Consequently the humidity therein was no doubt approximate to the one prevailing over the surface of the substance. From 10 to 50 eggs were used in each test and most of the tests have been repeated a number of times.

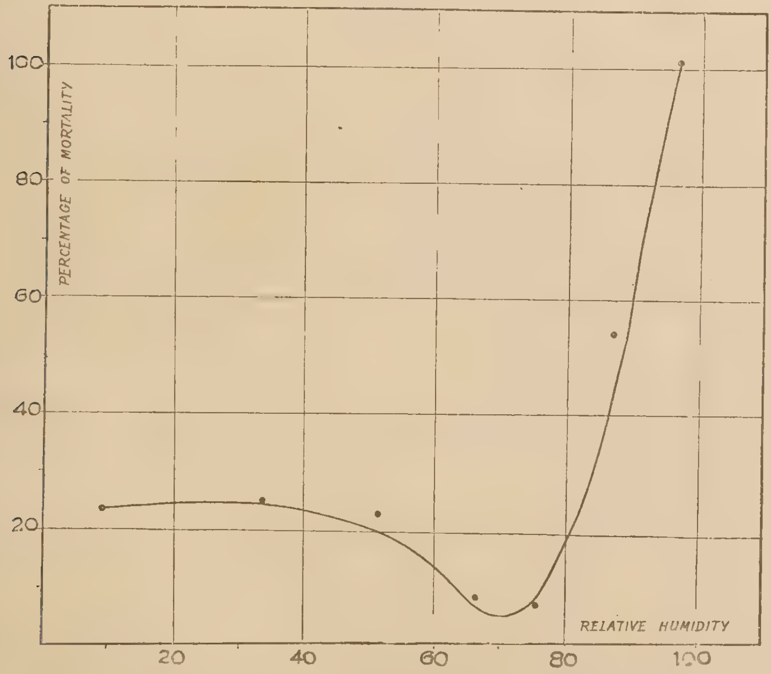

Fig. 1. Mortality of eggs of *Capnodis tenebrionis* at various degrees of relative humidity.

From these experiments it was evident that the relative humidity has no marked effect on the length of development of the egg at a temperature of 27°C. Most of the eggs, whether kept in total dryness or at a relative humidity of approximately 85 per cent., hatched simultaneously after a twelve days' incubation period.

The mortality of the eggs in these tests is shown in Table I and fig. 1.

TABLE I.

Effects of various Degrees of Relative Humidity upon Mortality of Eggs of C. tenebrionis.

Number of experiment breedings	Number of eggs	Substance to control humidity	Relative humidity attained	Number of eggs hatched	Percentage of mortality
5	150	Dry CaCl	Below 10%	116	23
3	100	Sat. sol. CaCl	About 33%	76	24
4	115	Sat. sol. $Na_2Cr\ O_7$	,, 52%	90	22
3	100	Sat. sol. $NaNo_2$	,, 66%	92	8
3	65	Sat. sol. NaCl	,, 75%	55	7
5	150	Sat. sol. $K_2Cr\ O_7$	,, 87%	70	53
4	125	Water	Above 95%	0	100

From these figures it is evident that the eggs are susceptible to high relative humidity since over 50 per cent. died at a relative humidity of 87 per cent., and none of the eggs survived in an atmosphere saturated with moisture. On the other hand it is significant that the eggs are developed even in total dryness. Only 23 per cent. died at the low relative humidity of from 0–50 per cent. The most favourable condition for the eggs is a relative humidity of from 60–80 per cent.

If we bear in mind the hygroscopic tendencies of salts such as calcium chloride and magnesium chloride which cover the egg shell, we can readily imagine how these absorb all the moisture from the atmosphere around the egg in order to protect it from drying. In fact microscopic examinations of eggs exposed to a high relative humidity showed the salt to be hygroscopic, and there is no doubt that this factor renders the eggs resistant to complete dryness for a period of over ten days. Just how much moisture may be absorbed by the egg shell may be seen from the following figures :—Fifty egg shells, after having been in a moist chamber for 24 hours, weighed 2·01 mg. The same eggs, which had been for 24 hours in a chamber containing absolute sulphuric acid, weighed 1·310 mg. In other words, 0·7 mg. of moisture had been absorbed by them, or over a third of their total weight.

Further breeding experiments were carried out in order to determine the effects of a high relative humidity when exposed to it for various lengths of time. Thus eggs were exposed for periods of one, two, three, four, five, six and seven days to a relative humidity of over 95 per cent. Subsequently they were removed to the prevailing relative humidity of the room, which was about 70 per cent., until the end of the incubation period. The results obtained are given in Table II and fig. 2.

It is apparent from these data that even a two days' exposure to high relative humidity increases the mortality of the eggs, and the longer the eggs are exposed to it, the higher is the mortality.

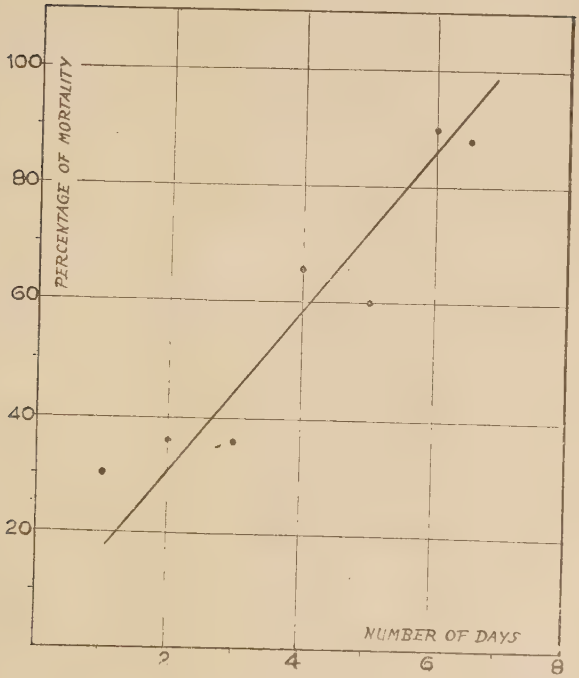

Fig. 2. Mortality of eggs of *Capnodis tenebrionis* when exposed to a high relative humidity.

TABLE II.

The Effects of a high Humidity upon Eggs of C. tenebrionis *when exposed for various Lengths of Time.*

Number of eggs	Length of exposure in days	Number of larvae hatched	Percentage of mortality
50	1	35	30
100	2	64	36
50	3	32	36
50	4	17	66
50	5	20	60
50	6	5	90
50	7	6	88

Effects of Temperature upon Eggs.

The optimum temperature for the development of the eggs is in the neighbourhood of 30°C., at which the incubation period is ten days. Though the eggs of *C. tenebrionis* developed within seven days at 35–37°C., the mortality of the eggs was then higher.

In a room, where the temperature fluctuated during the months of July and August between 26 to 32°C., giving an average of about 29°C., the incubation period of the eggs of *C. carbonaria* was 11 days ; while during the months of September and October, when the temperature averaged 26°C., it was 16.

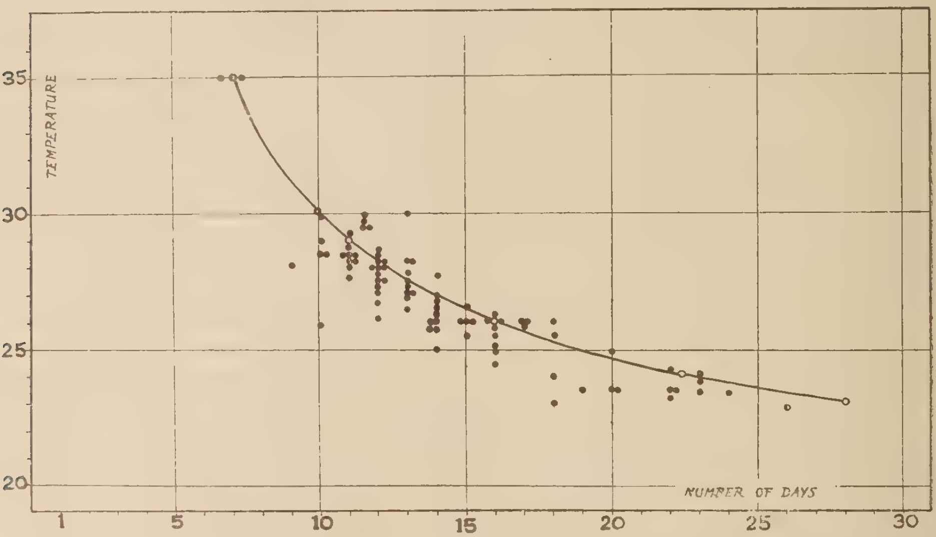

Fig. 3. Development of eggs of *Capnodis tenebrionis* at various temperatures.

Taking these values, it can be calculated on the Blunck formula, that the threshold of development is 19·4°C.

Laboratory breedings substantiate this precisely. Several eggs, which were laid during January 1937, were left in the room throughout this month and February. The temperature during January fluctuated between 10–18°C., giving an average of 13°C., and during February between 14–19°C., giving an average of 16·5°C. None of them from the several batches hatched—not even those laid early in February. The long exposure from four to nine weeks at a temperature below the threshold of development caused a gradual deterioration of the eggs. However, eggs laid at the end of February hatched early in April. The temperature during March fluctuated from 16 23°C., giving an average of 20°C. The hatching was considerably retarded, but 40 per cent. of the eggs hatched nevertheless.

If we plot the curve of the calculated hyperbola together with the empirical data obtained in the breedings at various times, we notice there is a close agreement. The incubation periods of *C. tenebrionis* and *C. cariosa* are more or less identical with that of *C. carbonaria*.

Resistance of Eggs to Low Temperature.

The fact mentioned above, that eggs exposed for some time to a low temperature gradually died altogether, suggested a test to discover how low must the temperature be and for how long must the eggs be exposed to it before they eventually die. Batches of 50 eggs of *C. tenebrionis* were placed in a temperature of 13°C. and removed after varying intervals, and subsequently placed at a temperature of 27°C. Other eggs were placed at a temperature of 6–7°C., and the tests were repeated similarly. The exposure of the eggs to cold brought about a mortality, the degree of which is shown in Table III.

TABLE III.

Mortality of Eggs of C. tenebrionis *when exposed to low Temperature at various Lengths of Time.*

At a temperature of 6–8°C.			At a temperature of 13°C.		
No. of days exposed	No. of eggs hatched	Percentage of mortality	No. of days exposed	No. of eggs hatched	Percentage of mortality
1	69	31	2	36	28
2	62	38	4	18	64
3	58	42	6	26	48
4	55	45	8	29	42
5	44	56	10	11	78
6	31	69	12	17	66
7	39	61	14	9	82
8	23	77	16	9	82
9	16	84			
10	8	92			

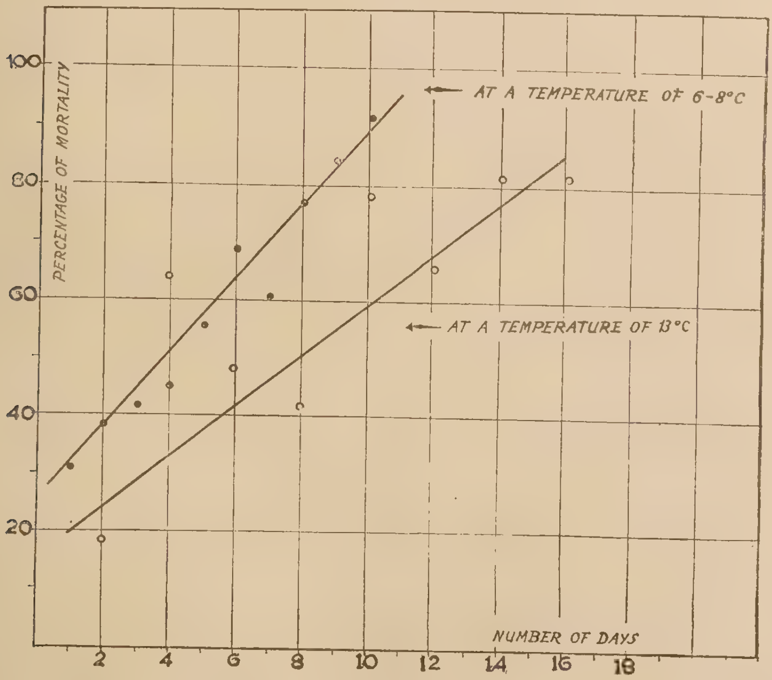

Fig. 4. Mortality of eggs of *Capnodis tenebrionis* when exposed to low temperatures.

From this table it is evident that it is sufficient for eggs to remain ten days only at the low temperature of 6–8°C. in order to bring about almost a 100 per cent. mortality, and that at 13°C., it requires at least eighteen days to produce the same results. These figures explain clearly the results of the breedings in the room during January and February 1937.

Resistance to High Temperature.

In experiments for studying the resistance of the eggs to higher temperatures, batches of 100 eggs of *C. tenebrionis* were placed at varying short periods in temperatures of 40°C., 46°C., and 50°C. ; on removal they were placed in the favourable temperature of 27°C. until they hatched.

The results are given in Table IV.

TABLE IV.

Survival of Eggs of C. tenebrionis *when exposed to various Degrees of high Temperature.*

Temp.	Two hours' exposure	Four hours' exposure	Six hours' exposure	Eight hours' exposure
40°C.	77	81	82	84
46°C.	88	75	76	72
50°C.	67	61	35	37

From this it is clear that temperatures of 40°C. and 46°C. are hardly injurious to the eggs when exposed to them for a few hours. It is also evident that they are quite resistant to a temperature of 50°C., at which over one-third survived after having been exposed to it for eight hours. However, the longer the period of exposure to these temperatures, the higher is the mortality, and there is no doubt that the eggs die within two days at 45°C.

Practical Considerations.

It has been pointed out above that the eggs of *Capnodis* die when exposed to a relative humidity above 87 per cent. Irrigated soil may create such conditions. Therefore if trees are irrigated and cultivated so that the soil around them is kept moist at long intervals during the summer, this condition may reduce the percentage of hatching to a great extent. In fact it has been reported from various sources that in those areas where irrigation has been introduced, the problem of *Capnodis* has diminished very considerably.

Summary.

The economic importance of *Capnodis* in Palestine is discussed ; the various species and their hosts are enumerated.

The egg is described and its shell chemically analysed. It was found that potassium, calcium and magnesium are present as cations and chloride and carbonate as anions.

The effects of relative humidity upon the egg are discussed. It is pointed out that the egg is resistant to a low percentage, but succumbs to a high percentage of relative humidity. The rôle of the egg shell in this matter is important.

The effects of the temperature upon the eggs are discussed. Their development at various temperatures is calculated, and the Blunck formula applied. The mortality of the egg at high and low temperatures is shown in tables.

THE INFLUENCE OF DROUGHT ON THE SURVIVAL OF EGGS OF *AUSTROICETES CRUCIATA*, SAUSS. (ORTHOPTERA) IN SOUTH AUSTRALIA.

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E+ A

1. Introduction.

In South Australia, *Austroicetes cruciata*, Sauss., occurs in a restricted climatic belt in which the season during which soil moisture is adequate for the active growth of plants lasts for only three to six months, during the winter and spring. The spring is short, and the summer is hot and dry (fig. 1).

Plagues of grasshoppers may develop as a result of a sequence of favourable seasons. Once a plague has developed, the grasshoppers may remain in plague numbers for several years. Drought is probably the most important climatic factor limiting the abundance of *A. cruciata* in the grasshopper belt in South Australia. Parasites and predators are not normally important, but birds may sometimes be responsible for completing the decline of an outbreak (Birch & Andrewartha, 1941).

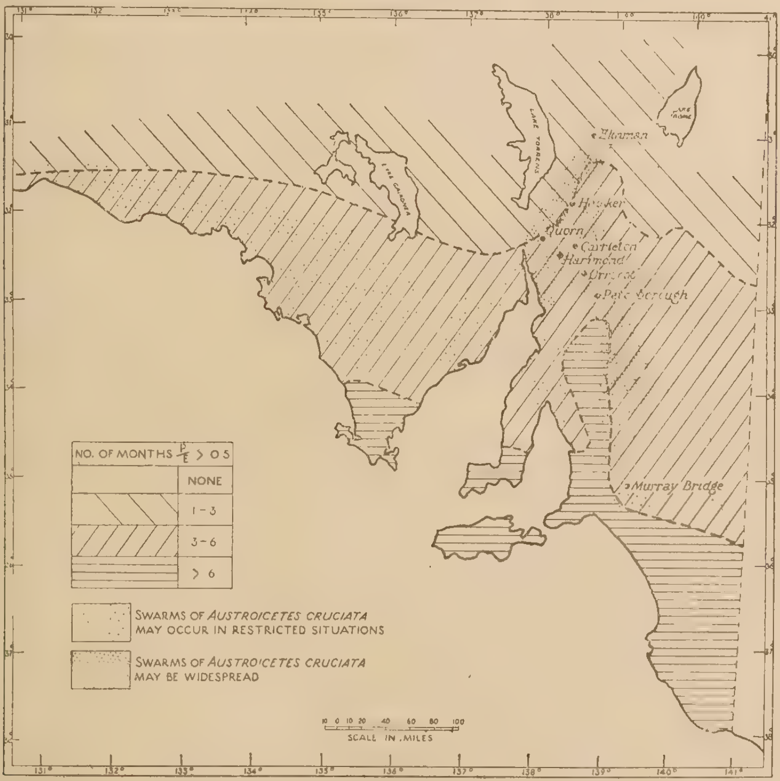
131°
132°
133°
134°
135°
136°
137°
138°
139°
140°
141°
LAKE TORRENS
LAKE GAIRDNER
LAKE FROME
Blinman
Hawker
Quorn
Carrieton
Hammond
Orroroo
Peterborough
Murray Bridge
NO. OF MONTHS P/E > 0.5
NONE
1-3
3-6
> 6
SWARMS OF AUSTROICETES CRUCIATA MAY OCCUR IN RESTRICTED SITUATIONS
SWARMS OF AUSTROICETES CRUCIATA MAY BE WIDESPREAD
10 0 10 20 40 60 80 100
SCALE IN MILES

Fig. 1. Map of part of South Australia showing the distribution of *Austroicetes cruciata* in relation to climate.

The influence of drought on the survival of nymphs has been discussed in an earlier paper (Birch & Andrewartha, 1941). In this paper we examine the influence of drought on the survival rate of the eggs.

The eggs of *A. cruciata* are laid in November; they remain in the soil for 10 months, hatching in the following September. During the summer the moisture content of the soil surrounding the eggs may remain below the wilting point continuously for months at a time; in dry years, this may occur also for periods during winter and spring. Thus the eggs may be exposed to desiccation at various stages of their development. The stage of development of the embryo is important in relation to the susceptibility of the eggs to desiccation (Birch & Andrewartha, 1942).

2. Survival Rate during the Summer.

The eggs are in diapause throughout the summer and until about the end of May (Birch, 1942). They are least susceptible to desiccation when in diapause, nevertheless the severity of the drought and heat during the summer months makes this period the most critical time for the eggs.

The Influence of Temperature.

It is unlikely that high temperature has ever been directly responsible for high mortality of eggs of *A. cruciata* in the field in South Australia. In January 1939 this State experienced a heat wave that set a new record for maximum temperature. At Yongala (near the southern limit of the grasshopper belt) the official highest shade temperature (in a Stevenson screen) was 111·1°F. recorded on 9th January. Unofficial records for other towns in the grasshopper belt were Quorn 115°F., Peterborough 112°F. At the Waite Institute, the highest maximum shade temperature was 108·2, recorded on 10th January; on the same day the maximum 1-inch soil temperature was 135·8°F. The average maximum shade temperature at the Waite Institute for January is 80·5°F. and the average maximum 1-inch soil temperature is 110·3°F. So it is likely that the highest 1-inch soil temperature in the grasshopper belt during the record heat wave of 1939 was of the order of 140°F. (60°C.). A field survey made in April 1939 showed that in three of the five places examined the mortality rate had been well under 50 per cent. (Table III)*.

These observations were consistent with the results of the following laboratory experiment with eggs in diapause. Eggs collected in November 1938 were kept at 20°C. and 75 per cent. relative humidity for three months and then treated as follows. Ten parcels of eggs were exposed to either 50°C. or 60°C. at 95 per cent. R.H. for periods varying from 15 minutes to 48 hours. The treatments were not replicated. The mortality rates are given in Table I.

TABLE I.

Showing the mortality rate of eggs in diapause when exposed to 50°C. and 60°C. (95 per cent. Relative Humidity) for varying periods.

60°C.		50°C.	
Duration of exposure	Percentage eggs dead	Duration of exposure	Percentage eggs dead
15 minutes	20	1 hour	2·5
30 ,,	15	2 hours	2·5
60 ,,	88	4 ,,	17·5
90 ,,	100	6 ,,	12·5
		24 ,,	45·0
		48 ,,	70·0

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* Hawker was the only place where 90 per cent. or more of the eggs were dead. It is unlikely that the temperature was higher there than elsewhere in the grasshopper belt. This higher mortality rate was associated with lower rainfall at Hawker (see below, p. 247).

In nature, temperatures of this order are not likely to be maintained long enough to kill a large proportion of the eggs.

The Influence of Moisture.

Indirectly high temperature may have an important influence on the mortality rate of eggs since the saturation deficit of the air in the soil spaces is high when the temperature is high and the soil moisture content low.

(*a*) *Soil moisture and the humidity of the air in the pore spaces.*

The moisture content of soil below the wilting point is related to the humidity of the air in the soil spaces. Curves showing this relationship are given in fig. 2. To obtain these curves, samples of about 7 grm. from two types of soil in which eggs are normally laid were placed in vacuum desiccators over five different concentrations of sulphuric acid at 30°C. ± 0·01°C. The equilibrium values for soil moisture were determined for soils that were drying and for soils that were absorbing water. The equilibrium values reached by drying are more important for our purposes.

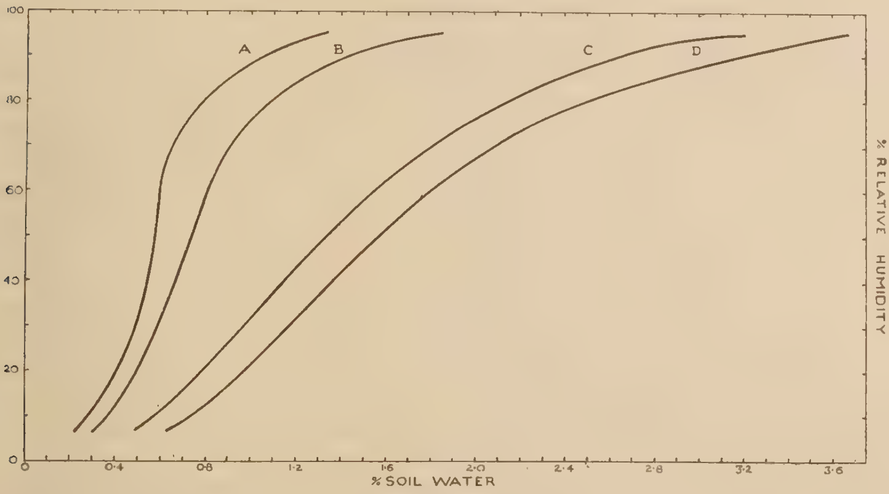

Fig. 2. Soil moisture (dry basis), vapour pressure curves for two types of surface soil from the egg-beds of *Austroicetes cruciata* : A. Sandy loam, wetting curve ; B. Sandy loam, drying curve ; C. Loam, wetting curve ; D. Loam, drying curve.

During summer the moisture content of the soil may be well below the wilting point. For example, soil sampled to a depth of 1 inch in two situations at Hammond on 3rd January, 1939, contained 0·98 per cent. and 0·76 per cent. water (on a dry soil basis). This corresponds to relative humidities of 21 per cent. and 11 per cent., respectively. With the high temperature that prevails through the summer, relative humidities of this order result in the eggs being exposed to saturation deficits of the order of 0·7 inches of mercury.

(*b*) *The influence of small falls of rain.*

It was shown in a previous paper that, when eggs in diapause were exposed for long periods in air with a high saturation deficit, the mortality rate was influenced largely by the amount of evaporation and also by the duration of the exposure to desiccation (Birch & Andrewartha, 1942). But there is no evidence that the vigour of the egg is impaired by intermittent exposures to sub-lethal periods of desiccation separated by wetting. Consequently it is important to know the minimum amount of rain that will penetrate dry soil to the depth of an egg-pod (about 2 cm.).

The following experiment was designed to evaluate the influence of small falls of rain. Three types of soil in which eggs are normally laid were chosen, namely, a loam and a sandy loam at Hammond and a loam at Orroroo. Quantities of water equivalent to falls of rain of 5, 10, 20 and 25 points* were sprayed on to the soil and the depth of penetration measured after half an hour. Three replicates of one square foot were used for each treatment ; nine measurements were made in each replicate. At Hammond the penetration of 10 points into the loam was measured at three sites chosen at random over an area of about one square mile. There was no significant difference between the three sites so the results have been considered together. In Table II the mean penetration in the three types of soil is given, together with water content of the soils at the beginning of the experiment and the moisture equivalent value for each soil. Because of the slow penetration of water into the consolidated loam at Hammond, the water had to be applied slowly and loss by evaporation was considerable.

TABLE II.

Showing the depth of penetration (in cm.) of various amounts of rain in three types of soil in which eggs of Austroicetes cruciata *are normally laid.*

Soil	Amount of rain in points				Original moisture content	Moisture equivalent of soil
	5	10	20	25		
Loamy soil (Orroroo)	0·7	1·0	1·5	—	1·85	16·82
Loamy soil (Hammond)	0·5	0·8	—	1·3	1·04	14·24
Sandy loam (Hammond)	0·7	1·2	2·0	—	0·99	8·80

A fall of rain of 20 points was necessary to wet the loam at Orroroo and the sandy loam at Hammond to the depth of an egg-pod ; on the loam at Hammond more than 25 points was necessary. These figures are comparable with those given by Cannon (1921). He found that the maximum penetration in soil with a " large percentage of sand " following a shower of 21 points was of the order of 3·5 cm. He does not state the moisture content of the soil before the rain fell. Working at Koonamore, Osborne, Wood & Paltridge (1935) considered that " falls of less than 25 points do not penetrate more than 2–3 cm."

(*c*) *The survival rate of eggs during the summer of* 1938–39.

The summer of 1938–39 was unusually dry, particularly at Hawker and Hammond (Andrewartha, 1940). A survey made in April 1939, showed that 91 per cent. of the eggs at Hawker had been killed by the summer drought ; at Hammond the mortality rate varied from 54 per cent. to 75 per cent., depending on the local situation (Table III). More eggs were alive in the lighter soils and where the eggs had been laid up against stones. Light falls of rain were more effective in moistening the eggs laid in these situations.

(*d*) *The occurrence of high mortality due to drought during the last* 50 *years.*

The results of the survey reported in Table III were used as a basis for an analysis of the meteorological records for the past 50 years for six representative stations in the grasshopper belt. The daily rainfall and the estimated mean daily evaporation were used to estimate the longest dry spell between 1st November and 30th April. The mean daily evaporation was estimated from standard records for mean monthly temperature and humidity, using methods described in earlier publications (Andrewartha, 1940; Birch & Andrewartha, 1941). Only the longest dry spell was considered, since observations have shown that eggs regain their normal vigour when they are moistened after an exposure to desiccation that had been insufficient to kill them. A dry spell was defined as the period during which the soil moisture content was estimated to be below the wilting point. Starting with any fall of rain sufficient to wet the soil to a depth of an egg-pod, daily falls of rain were summed, and estimated daily evaporation from the soil was subtracted until zero was reached; the dry spell was considered to have started from this point. The evaporation from the soil was taken as half that from a free water surface. The evaporation was estimated from the relationship $E=14{\cdot}7$ S.D. A fall of rain greater than half the estimated daily evaporation from a free water surface was considered sufficient to break a dry spell. In ten of the dry spells shown in Table IV insignificant falls of rain were recorded. These never exceeded 10 points and were always less than one-quarter of the estimated daily evaporation from a free water surface. Since the results given in Table II indicate that it requires more than 10 points of rain to wet the soil to the depth of an egg-pod, these small falls were ignored for the purpose of this analysis.*

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* A " point " is used to designate 0·01 inch of rain.

TABLE III.

Showing the mortality rate of eggs of Austroicetes cruciata *in the field. Observations made in April* 1939.

Place		Percentage eggs dead	
Hawker	A ...	93·6	91%
,,	B ...	88·4	
Hammond	A ...	75·4	64%
,,	B ...	63·1	
,,	C ...	54·1	
Burra	...	31·0	31%
Peterborough	A ...	40·3	36%
,,	B ...	39·5	
,,	C ...	28·9	
Orroroo	A ...	18·0	22%
,,	B ...	25·1	

In Table IV the length of the longest dry spell and the total estimated evaporation from a free water surface are shown for all the years in which the estimated evaporation for the most severe period of desiccation exceeded 26·2 inches—the figure for Hammond 1938/39. An asterisk marks the years in which the evaporation during the longest dry spell exceeded 40·6 inches—the figure for Hawker 1938/39. The value of 26·2 inches was chosen because it was considered that the drought at Hammond in the summer of 1938/39 was nearly critical (see Table III). The value of 26·2 inches was exceeded from 5 to 16 times during the last 50 years, depending upon the district. In the same period the value of 40·6 inches was exceeded from one to seven times, depending on the district.

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* These small falls of rain would raise the humidity of the air in the pore spaces of the top few millimeters of soil. Convection currents and diffusion may tend to raise the humidity in the air around the eggs and thus reduce for a time the aridity of the egg's environment. But these effects would last for less than a day and would be negligible.

TABLE IV.

Showing years since 1890 *for six towns in the grasshopper belt when the severity of the longest dry spell between* 1*st November and* 30*th April was greater than at Hammond and Hawker,* 1938/39.

Year	Hawker		Carrieton		Hammond		Quorn		Orroroo		Peterborough	
	Days	Total evap. (ins.)	Days	Total evap. (ins.)	Days	Total evap. (ins.)	Days	Total evap. (ins.)	Days	Total evap. (ins.)	Days	Total evap. (ins.)
1892/93	107	37·2					75	26·9	109	34·9	117	31·0†
1894/95							87	26·0				
1896/97							99	31·0				
1897/98	133	45·0*	97	38·5			71	32·2	113	44·1*		
1898/99			98	34·6	91	39·1	104	41·0*				
1900/01			83	29·0	81	32·7	114	42·8*	119	37·6†		
1901/02			92	30·3			82	29·5				
1905/06	110	39·6	105	36·0	117	40·1	102	40·7*	105	36·0		
1913/14							83	30·3				
1914/15			75	26·3	73	30·7	68	26·8	67	25·5		
1915/16	116	39·6†	114	32·6	141	51·4*	111	50·5*	96	28·4	97	27·0
1918/19	102	42·9*							106	41·9*†		
1921/22	114	37·9	101	39·0†	99	41·3*	79	34·6	76	26·5	81	26·9
1922/23			70	30·2	88	40·6*†	98	43·7*	69	29·9†		
1924/25					78	33·3						
1925/26	96	40·7*	97	36·2			95	38·9			119	38·6
1926/27							141	52·8*†				
1928/29	154	71·1*	83	35·1	154	50·5*†	154	63·0*	85	32·3	85	29·0
1931/32			63	26·7								
1932/33	74	28·8	124	44·2*	124	49·4*						
1938/39	80	40·6*†										
1939/40	66	34·1										
No. of years evap.>26·2 in.	11		13		10		16		10		5	
No. of years evap.>40·6 in.	5		1		5		7		2		0	

* As severe as Hawker 1938/39.

† Insignificant amounts of rain fell during these dry spells but they never exceeded 10 points and were always less than one-quarter of the mean daily evaporation.

3. The Survival Rate during the Winter.

Water is lost more rapidly from eggs in which diapause has been eliminated, but even at that stage of the development, prolonged exposure to low humidity is required to kill 50 per cent. of the eggs (Birch & Andrewartha, 1942).

Diapause is eliminated from eggs in the field by about the end of May. From the beginning of June onwards the eggs are less resistant to desiccation than during the diapause stage. But between May and September when the eggs hatch, the saturation deficit of the air in the pore spaces of the soil is low. It is therefore unlikely that drought has ever caused high mortality of the eggs at this time of the year.

4. The Survival Rate during the Spring.

It is a common observation that nymphs may emerge immediately after a shower of rain—even a few points being sufficient. During a dry spell the surface of the soil becomes firmly caked ; thus nymphs that hatch from eggs during a dry spell may be unable to push off the cap of the pod until the surface of the soil has been moistened by rain. For example, at Orroroo in September 1940, nymphs hatched in soil containing 2·7 per cent. moisture (this corresponds to 90 per cent. R.H. in the pore spaces) but they were not able to push the cap off and emerge from such dry soil. It has been shown that two points of rain may moisten the soil to a depth of 2 to 3 mm. (Table II); this is sufficient to moisten the cap of the egg-pod.

The survival rate of *Austroicetes cruciata* at this stage of its development may depend upon the duration and frequency of periods without rain and on the length of time that nymphs trapped in an egg-pod may remain alive.

In the laboratory 60 newly-emerged nymphs were exposed without food in air of 75 per cent. R.H. and at 20°C. The duration of life varied from three to eleven days. The mean duration of life was six days. In this experiment the saturation deficit of the air was higher than that which is likely to be experienced in the field. For example, the mean air temperature at Hammond for August is 13·2°C., for September 14·4°C. The mean relative humidity at Yongala is 74 per cent. for August and 64 per cent. for September. So six days is probably an underestimate of the duration of life in the field of nymphs imprisoned in an egg-pod.

Nevertheless, when this figure was used as the basis for an analysis of the meteorological records for the past 50 years for six representative stations in the grasshopper belt, it was shown that the probability of a high mortality rate being caused by "drought" at the time of hatching was only of the order of 1 per cent.

For the purposes of this analysis, the records of daily rainfall at Hawker, Quorn, Carrieton, Orroroo, Hammond and Peterborough were examined for the 50 years 1891–1940. The frequency of occurrence of six-day "droughts" was determined, using the criterion that any period for which less than 2 points of rain was recorded was a "drought." Only the period during which eggs of *A. cruciata* normally hatch was considered, *viz.*, from 15th August to 20th September. The data were smoothed

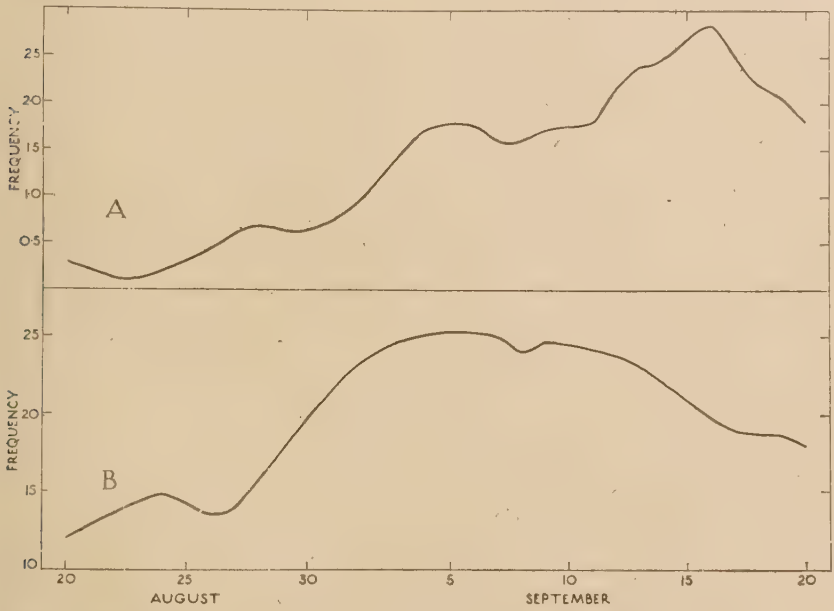

Fig. 3. Showing: A. The number of times during the 50 years, 1891–1940, that a six-day drought began on each day between 15th August and 20th September; and B. The estimated number of times during the same 50 years that the peak emergence of eggs of *Austroicetes cruciata* occurred on each day.

by the method of progressive averages and expressed as a frequency curve. The frequency of "droughts" was plotted against the date on which the six-day "drought" began (see fig. 3).

A similar frequency curve was constructed for the date of hatching of the eggs. Using the methods of temperature summation described elsewhere (Andrewartha, 1943), the date of hatching (*i.e.* of "peak" hatching) of eggs was estimated for each of the 50 years. The data were smoothed by the method of progressive averages and expressed as a frequency curve with the frequency of hatching plotted against the date.

Now the probability for any given date that the beginning of a six-day drought will coincide with the peak hatching of the eggs is the product of the probabilities of those two events for the appropriate day. If for any given date the probability that the peak hatching will occur is H, and for the same date the probability that a six-day drought will begin is D, then the probability that the two will coincide on that date is H × D. And the probability for any one year that the peak hatching will coincide with the beginning of a six-day "drought" is $\frac{\Sigma \text{ H.D.}}{\text{N}}$ where N is the number of observations.

For Hawker the value $\frac{\Sigma \text{ H.D.}}{\text{N}}$ based on the 50 years 1891–1940 was 0·012. This means that heavy mortality of nymphs trapped in egg-pods might be expected 12 times in a thousand years. The analysis was not done in detail for the other stations since an inspection of the frequency curves showed that the value of $\frac{\Sigma \text{ H.D.}}{\text{N}}$ would in every case be lower than that for Hawker.

5. Summary.

Drought is the only factor in the environment of the eggs of *Austroicetes cruciata* that is likely to cause a high mortality rate of the eggs in the field.

The eggs may be exposed to drought at various stages of their development. The probability of high mortality due to exposure to drought during the winter is considered to be negligible.

The probability of a high mortality rate due to drought when the nymphs are hatching is unimportant. From an analysis of the meteorological records for 50 years, it was estimated that high mortality rates from this cause may occur 12 times in a thousand years at Hawker and less frequently elsewhere in the grasshopper belt.

The eggs are exposed to the most severe hazards during the summer. An analysis of the meteorological records shows that severe mortality rates may have occurred as a result of drought in the summer from one to seven times during the 50 years 1891–1940, depending upon the district.

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A TECHNIQUE FOR BIOLOGICAL STUDIES OF CHEESE MITES.

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Recent investigations on the control of cheese mites in New Zealand have necessitated detailed biological studies of the species concerned. Experiments have been carried out on the physical ecology of the species, *Tyrophagus longior*, Gerv., *Tyrolichus casei*, Oudm. [*Tyroglyphus siro*, auct.] and *Tyroglyphus farinae*, Degeer. A technique has been developed whereby, under controlled temperature and humidity conditions, individual developmental records may be readily obtained for all stages of the life-cycle. This technique is one that may be modified for similar studies on small insects, such as Thysanoptera, Collembola, etc.

Apparatus.

Temperature Control.—Material reared at all temperatures up to 15°C. was held in a large refrigerator cabinet in which there was a temperature variation of ± 1·5°C. All experiments at higher temperatures were carried out in thermostatically controlled electric incubators in which the temperature range was no greater than ± 1°C. about the mean.

Humidity Control.—In order to maintain constant humidity conditions during rearing, material was suspended in small, wide-mouthed preserving jars, 9 cm. in height and 7 cm. in diameter, above solutions of sulphuric acid and water. Solutions required to produce different relative humidities were prepared according to the table given by Buxton & Mellanby (1934).

The use of acid solutions for the control of humidity could not be regarded as wholly satisfactory, in view of the possibility of vapour from the acid or from impurities proving detrimental to the development of the living material handled. This point was checked at the commencement of the experiments. Three sets of material were reared at approximately the same relative humidity, one in a jar above an acid solution, one above a salt solution, and one exposed to the atmosphere within the incubator cabinet. The mortality recorded in each case was between 5 and 10 per cent., and there was no appreciable difference in the mean times of development. This experiment was repeated a number of times with similar results. It was concluded that, with the low concentrations of acid in solutions used to maintain the high relative humidities necessary for rearing Tyroglyphid mites, the quantity of vapour present would be so small as to have a negligible effect.

Rearing Cells.—Requirements for a suitable rearing cell were found to be as follows :—

(1) The material of which it was constructed had to be permeable to air and water vapour, so that a constant humidity could be maintained within the cell.

(2) At the same time this material had to be of such a texture as to prevent the escape of extremely small larvae.

(3) The cell had to be of such a shape that the whole interior could be readily examined under a microscope.

(4) There should be as few joins as possible, and these must be able to be perfectly sealed.

The original cell used by Michael (1901), consisting of a glass ring cemented to a microscopic slide and enclosed by a coverslip, was unsuitable as it did not permit humidity regulation. A section of glass tubing with bolting silk or brass gauze ends, as utilised by Hickin (1941) for work on Ptinid beetles, was also unsatisfactory, as neither bolting silk nor gauze was procurable of sufficiently fine mesh to prevent the escape of the extremely small larvae.

A number of other types of cells were experimented with, *e.g.*, square glass cells with cloth ends, plaster of paris cells, cells of fine mesh brass gauze soldered above to metal rings and lined with filter paper, etc. All these proved unsatisfactory, as each failed to comply with one or another of the above requirements.

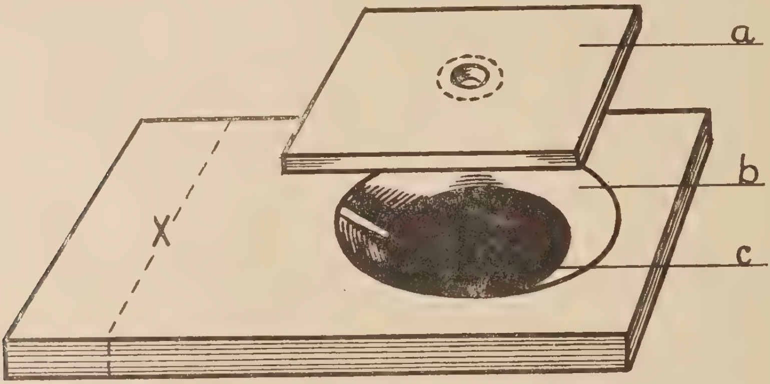

Fig. 1. *a*, glass cover ; *b*, inclined cell wall ; *c*, filter paper base.

Eventually a simple cell (fig. 1) was developed which has proved satisfactory in all experiments up to the present. This is constructed from a rectangular strip of one-eighth inch fibre or bakelite, of which the dimensions may be varied according to the requirements of particular experiments. Strips of either 2·5 by 4·5 cms. or 3·5 by 5·5 cms. have been most generally used in the current investigation. Towards one end, a round hole with sides inclined to the base at an angle of up to 45° from the vertical, and of an upper diameter of 1·5 to 2·5 cms., is cut through the fibre strip. Black filter paper is pasted over the lower surface of the fibre, thus providing a permeable base to the incised cell. The junction of the inclined wall and the filter paper cell base is completely sealed by a film of gelatine size. The cell is enclosed above by a glass cover held in position by a smear of paraffin and vaseline mixture round the upper margin.

Cell Carriers.—Each humidity jar will accommodate two cells, which are suspended above the acid solution by means of a carrier (fig. 2) designed to permit exposure of the permeable cell bases to the atmosphere of the jar. The carrier used is constructed from tin painted with white enamel. An upper disc, 8 cm. in diameter, fits over the top rim of the jar beneath the lid. Two vertical supports, 4 cm. in length and 5 cm. apart, are soldered to the under surface of the disc. These supports carry two horizontal three-sided trays, approximately 2 cm. apart. One cell is held on each tray by means of a rubber band passed around the base of the tray and over the end of the cell (at X). The portion of the tray beneath the filter paper cell base is cut away so that the base is free in the interior of the jar.

Technique for Studying Egg Development.

At the commencement of studies on the biology of Tyroglyphid mites, it was found that, if a number of adult mites was confined in a cell, they would readily oviposit on the coverslip. This was utilised in developing a technique for obtaining cultures of eggs suitable for physical ecology investigations.

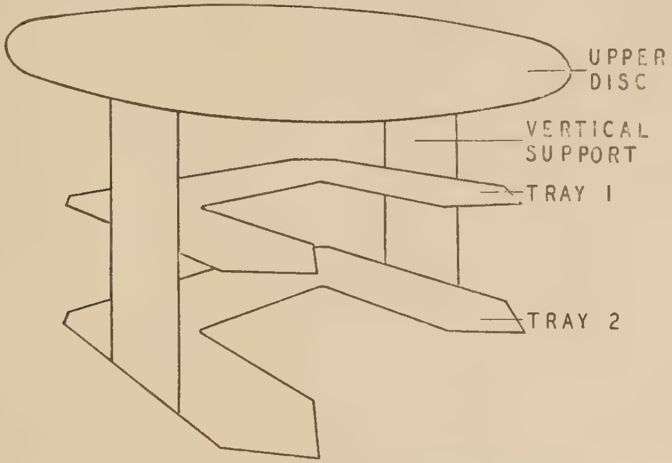

Fig. 2. Cell carrier.

The culture cell used is illustrated in fig. 1. It is constructed, as described above, from a fibre strip 2·5 by 4·5 cm. The square cell cover, cut from a fine microscope slide, has a hole of approximately 2 mm. diameter bored through the centre. In obtaining one series of eggs, five or six of the above cells are set up with the covers sealed in position. A number of adult mites (40 has proved satisfactory in the experiments carried out) are introduced into each cell as follows: Mite material of a known species is brushed from the surface of infested cheese on to a sheet of black glass where, with the aid of a pocket lens, adults are separated from the mass of larvae, nymphs and eggs. Each adult is picked up on the end of a fine needle, inserted through the aperture in the cover and released in the interior of the cell by means of a sharp flick with a second needle. The most satisfactory needles for this purpose are dental nerve canal broaches fitted into entomological needle holders.

After introduction of the required number of adult mites, the opening in the cell cover is sealed with a circle of cellophane. Cells are incubated at constant temperature and humidity usually for a period of three hours. Each is then examined and, where ten or more eggs are found on any cover, the latter is removed from the cell, inverted so that the eggs are uppermost and attached over a square of black paper towards one end of a microscope slide (fig. 3). The black paper is divided into squares by white lines, the small squares being numbered horizontally and lettered vertically so that each egg on the cover can be located.

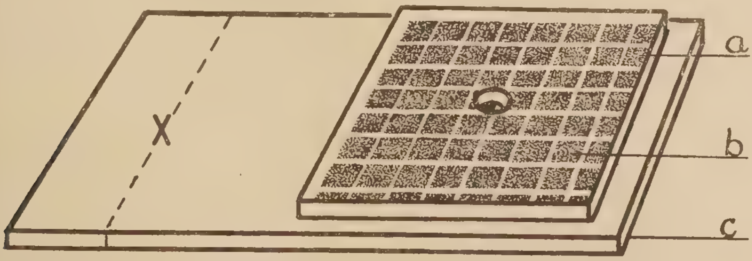

Fig. 3. *a*, inverted cover ; *b*, squared paper ; *c*, microscope slide.

Slide preparations of eggs are attached to carriers and incubated at the required temperature and humidity. During hatching, material is examined hourly. The time of development for each egg is calculated from the commencement of the period of oviposition to the end of the hour during which emergence of the larva occurs.

Technique for Studying Larval and Nymphal Development.

Larvae and nymphs are reared in larger cells (fig. 4) constructed from fibre strips 3·5 by 5·5 cm. and with plain, square glass covers. The base of the cell is divided into six sectors by lengths of horse-hair attached at the ends with drops of gelatine size. These sectors are numbered around the cell wall to facilitate rapid examination of the cell and location of individuals which have commenced the resting period terminating the larval, protonymphal and deutonymphal stages of development.

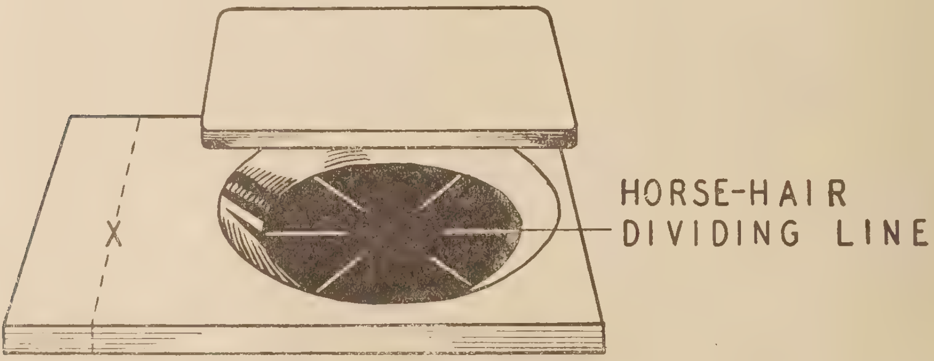

Fig. 4.

Cheese cannot be used as a food substance on account of the surface butterfat extruded at high temperatures, and the probable effect of its high moisture content on the relative humidity in the cell. Dried milk has proved to be the most suitable substance for use in developmental studies. This is introduced into the base of the cell in a fine film, obtained by brushing the material through fine-mesh gauze. Its general constitution is not altered within the temperature range required, and such a small quantity is introduced that it can have no appreciable effect on the relative humidity in the cell. In addition, its particles are so small that even minute larvae are not hidden beneath them.

An experiment on the length of development of any one stage is commenced from a single stock culture of eggs laid within a period of eighteen hours. Twenty to thirty eggs are placed out in each of a series of cells, and the emerging mites are reared through to the end of the stage preceding the one required. A second series of cells is set up, and five mites which, within the preceding three hours, have completed the moult marking commencement of the required stage, are transferred to each cell. The resting period at the termination of the stage is recorded, together with the hour during which the succeeding moult occurs.

Microscopic Examination of Living Mites.

In the course of comparative biological studies of mite species, relative measurements of developmental stages were required. Some difficulty was experienced in immobilising active stages prior to measurement. All mounting methods proved unsatisfactory, as, with the delicacy of the cuticle, particularly in the larvae, distortion of the body outline could not be prevented. Eventually the following technique was adopted :—

Living material is placed in small metal cells and held in a refrigerator at −1° to 2°C. for from two to three hours. In order to maintain the low temperature during microscopic examination and measurement, each cell is placed on a small metal strip (*i.e.* cell plate) inserted in the cork insulation of a box filled with ice (fig. 5). The outside dimensions of this box are 8·5 cm. wide by 15·5 cm. long by 4 cm. deep, the width being such that the box will fit between the stage arms of a binocular microscope. Inside, the box is constructed from tin 7 cm. by 14 cm. by 2·5 cm. deep. A plate of sheet brass 7 cm. by 4 cm., on which the cell is placed during examination, is soldered across one end. The remainder of the top is covered by a hinged lid extending to the free margin of the cell plate. The outside of the tin is coated with pitch to which a layer of cork is applied over the sides, base and lid, so that only the small cell plate is exposed. With the exception of this plate, the box is painted with enamel both inside and over the cork covering. When the box is filled with ice or with salt and ice mixture, for some considerable time the cell plate remains sufficiently cold to prevent the living material in the metal cells from becoming active.

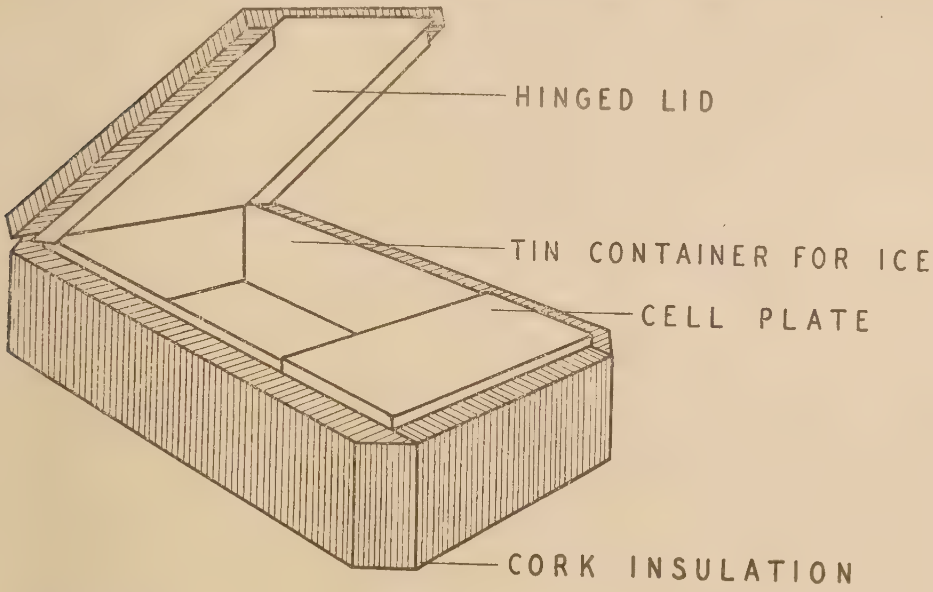

Fig. 5.

Acknowledgment.

The writer wishes to express her indebtedness to Mr. B. B. Given, Division of Entomology, Department of Scientific and Industrial Research, for his advice during discussions on the technique developed and considerable assistance in making the equipment required.

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APHIDIUS GRANARIUS, MARSH., IN RELATION TO ITS CONTROL OF *MYZUS KALTENBACHI*, SCHOUT.

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Introduction and Methods.

This paper has arisen from a critical study during 1941–43 of the Aphid, *Myzus kaltenbachi*, Schout.,* as a major pest of winter cereals in the South Wales Province, where this Aphid was subsequently found to be heavily parasitised by a Braconid. The observations have been made primarily from the standpoint of the relationship existing between host and parasite, and as such have involved the study of the bionomics of the latter. A colony of the parasite was bred out on its host, *Myzus kaltenbachi*, under glass chimneys in the laboratory, and identified by Mr. G. E. J. Nixon of the Imperial Institute of Entomology as the Braconid, *Aphidius granarius*, Marsh.

The material was investigated *in situ* or dissected, mounted and stained in the usual manner. Sections were cut with a microtome and stained with haematoxylin and 1 per cent. eosin in alcohol.

The respiratory system of the larva was studied by allowing a drop of Puthrie's fluid to flow over it and covering with a watch glass. The slide was gently warmed over a bunsen flame for two to three minutes and the subsequent clearing process watched through a binocular microscope. In 30 to 35 minutes the tracheal system appeared as a network of shining white tubes.

The Imago.

(*a*) *Emergence.*—The parasite emerges from the parasitised Aphid generally through the abdominal dorsum, where a circular portion of the cuticle is removed by means of the parasite's mandibles. The average diameter of the aperture, so constructed, varies from 0·6 to 0·7 mm., but often the cut disc remains attached by a small hinge. In 89 per cent. of the cases examined, this disc was completely removed, but even where complete removal was effected, the cut cuticle was worked loose in the majority during the process of liberation.

Directly on leaving the Aphid body, the imago is soft and covered with a sticky exudation. The body takes some five to seven minutes to dry and expand. During this period the insect is extremely active, stopping its hurried movements only at irregular intervals, when it "preens" the abdomen with the metathoracic legs and the head and thorax with the pro- and mesothoracic appendages. The antennae, meanwhile, are in a constant up and down movement, occasionally being drawn between the tibial spine and femoral groove of the prothoracic leg. About four minutes after emergence, the wings begin to assume final shape and are stroked by the metathoracic legs, with preliminary wing movements occurring after some seven to ten minutes, but no flight is undertaken until the wings are fully inflated and dry.

(*b*) *Mating.*—After a minimum of two hours, mating takes place, and out of 179 matings noted, 159 took place within three days of emergence, 12 within nine days, and the remainder, comprising 13 females and 15 males, refused to mate during their lifetime. The Hymenopteron does not appear to be influenced to any great extent by light conditions, and it was seen to mate both in daylight and artificial light.

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* Kindly identified by Mr. F. Laing of the British Museum.

The male climbs on to the back of the female grasping the thorax near the wing bases with the anterior pair of legs. The second pair of legs are curved around the abdomen, and by crawling backwards the apex of the male abdomen curves forwards and downwards to meet the tip of the abdomen of the female. Two males may often try to mate with a single female, and on occasions when males are confined under glass chimneys, for more than four days, they will try and mate with each other. Vigorous attempts by the female to escape from the male are evident before mating, and sometimes even after a connection has been established. The same female may be mated more than once with the same or different males.

Copulation was observed in 1,324 instances, when it lasted between 23 and 72 seconds. One pair remained connected for 135 seconds, and another for three minutes. Directly following mating, the male retracts its genitalia and may fly away at once. The female remains in the same place for a few minutes and continually strokes the abdominal tip with the metathoracic leg.

(*c*) *Oviposition.*—Under laboratory conditions (temperature of 67°F.), oviposition takes place within 5 to 87 minutes after copulation, while an unmated female laid eggs some three hours following the first flight. Continued oviposition takes place in the first two or three days after emerging, subsequently decreasing in its intensity. Provided that the Aphids are numerous, a high degree of parasitism results, but with fewer hosts available, the number of recorded " strikes " per individual is greater, and more than one egg may be deposited in each Aphid. In general, however, the females avoid hosts that have already been parasitised.

The number of eggs laid by a single female varied from 153–382, but the number of " strikes " often greatly exceeded this.

(*d*) *Prematuration Mortality.*—Investigations on this aspect of the work were conducted in the laboratory, under conditions resembling as closely as possible those found in the field. A number of Aphids (200 per colony) were raised in glass cages, free from parasitic influence. After five days two previously mated female Braconids were introduced, and with the onset of the moribund stage of the host following parasitism, the latter were removed to petri dishes containing moistened filter papers. Here they were retained for 40 days, when all the potential imagines had emerged from the sessile Aphids. The results obtained are indicated in Table I.

TABLE I.

Prematuration Mortality of the Imagines of Aphidius granarius *under laboratory Conditions* (*Temperature* 65°*F.*).

Series.	No. of Aphids introduced	No. of Aphids parasitised	No. of adult parasites emerged	No. of prematurely dead parasites
1	200	172	134	38
2	200	184	132	52
3	200	194	160	34
4	200	197	152	45
5	200	190	160	30
6	200	191	181	10
7	200	183	161	22
8	200	181	174	7
9	200	199	189	10
10	200	187	169	18
Totals	2,000	1,878	1,612	266

Prematuration mortality under such circumstances amounts to 14·2 per cent. in the absence of predators and hyperparasites. Death in 253 specimens occurred in the pupal stage, five in the prepupal stage, and eight in the mature larval stage. The local distribution of the parasite would *a priori* be expected to depend primarily on biotic factors. As a parasite it is dependent on the presence of its hosts and enemies (both parasitic and predatory), and the latter might be expected intimately to affect its numbers, since it is exposed to their attacks both in the host and free living stages.

Examination of the prematurely dead specimens in the above experiments yielded no evidence of the effects of hyperparasitism, nor did field collections. There is, however, circumstantial evidence that in the field some of the parasites fall victims to predacious insects, mainly *Coccinella septempunctata*, L., *Adalia bipunctata*, L., and Syrphids, during the premoribund phase of the host. Birds also, particularly starlings, are known to feed on these parasites at this stage. Field mice may devour the parasitised Aphids, more particularly when the latter have attained the sessile stage. In general, these were not sufficiently numerous seriously to affect the survival potential of the parasite and may therefore be disregarded.

It would thus appear that *Aphidius granarius* does not suffer markedly from either individual or inter-specific competition, being comparatively free from hyperparasitism, and because of the absence of any marked gregarious tendency of the host is relatively free from devastating attack by predators. The significant variables in its environment, unlike those of its predators, would therefore appear to be physical rather than biotic. Among such eliminating factors would be desiccation, thermal extremes, accident or mechanical injury and so on.

Biology and Bionomics of the Immature Stages.

The egg (fig. 1) is oval, white, slightly flattened at one end, devoid of spines, sculpturing or processes of any kind, and possesses a loosely fitting chorion (ch.ov.).

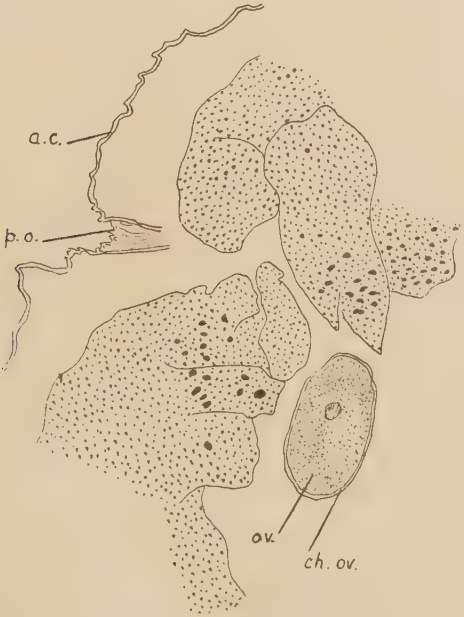

Fig. 1. Egg *in situ* in host tissue. a.c., Aphid cuticle; p.o., point of insertion of ovipositor; ov., egg; ch.ov., chorion.

The length of 23 eggs varied from 0·049 mm. to 0·06 mm. and the breadth from 0·012 mm. to 0·025 mm. Generally it is deposited in the abdominal cavity of the Aphid, and in only 2 per cent. of the specimens investigated did deposition take place in the thorax. The cuticle (a.c.) of the host is pierced by the ovipositor and the egg transported directly into the haemocoele. The eggs float freely in the body fluids of the host, movement being facilitated by the peristaltic action of the intestine and circulating fluids. At 67°F. hatching of the egg takes place within 4–6 days after oviposition.

The process of ecdysis is difficult to follow owing to the extreme tenuity of the cuticle ; it appears as in some other internal parasites to take place by the backward sloughing of the exuvia. In view of these difficulties observations on the larval development were based on changes in general form, size and internal modifications.

The duration of the various stages in the laboratory at 67°F. was as follows :—

1st larval stage		...	3 to 4 days.
2nd ,,	,,	...	3 days.
3rd ,,	,,	...	3 to 5 days.
4th ,,	,,	...	4 days.

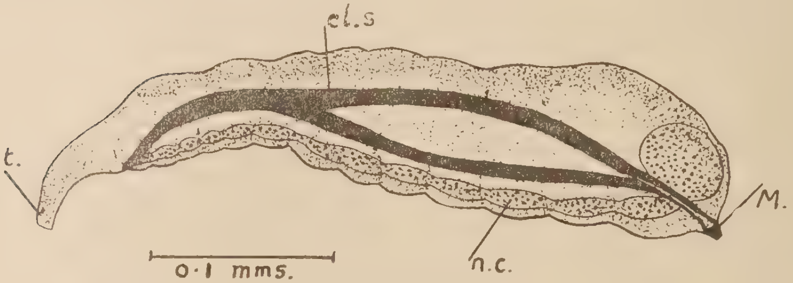

Fig. 2. First-stage larva of *Aphidius granarius*, Marsh. : cl.s., alimentary canal ; M., mouth ; n.c., nerve cord ; t., tail appendage.

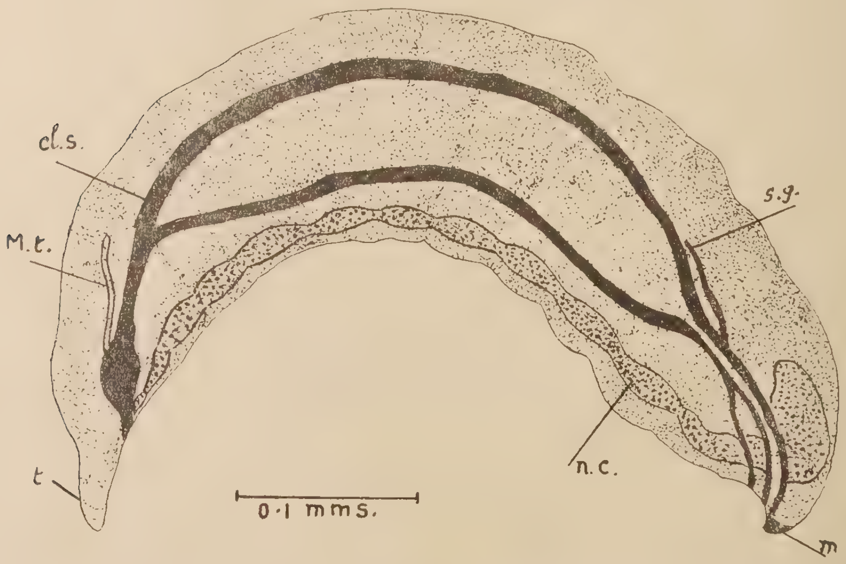

Fig. 3. Second-stage larva of *A. granarius*, Marsh. : t., tail appendage ; M.t., Malpighian tubules ; cl.s., alimentary canal ; s.g., salivary gland ; n.c., nerve cord ; m., mandible.

The first larval stage (fig. 2) is, immediately after hatching, semi-translucent, comprised of 13 segments, elongate, tapering from the anterior to the posterior end, with the last abdominal segment terminating in a reduced tail-like appendage. The body integument is soft and delicate and has no spiracles. The caudal appendage of other Aphidiinae has been the subject of considerable discussion, Tothill (1922), Timberlake (1910) and others have associated it with a respiratory function, but this has been recently discredited by Thorpe (1932). Seurat (1899) attaches to it a locomotory function, while Weissenberg, quoted by Tothill (1922), endows it with a capacity to store excretory products.

The second larval stage (fig. 3) differs from the former by an increase in size, a more pronounced curvature and a conspicuous reduction of the cauda. The latter becomes gradually resorbed as growth of the second instar proceeds, disappearing completely in the third stage. During the course of routine dissections, it was noted that no material injury is caused to the Aphid tissue by the first-stage larva. The parasite appears to sustain itself on the blood and serous fluids of the host. With the onset of the second larval period, feeding on the adipose tissue and host embryos takes place, this condition becoming more emphasised in the third-stage larva.

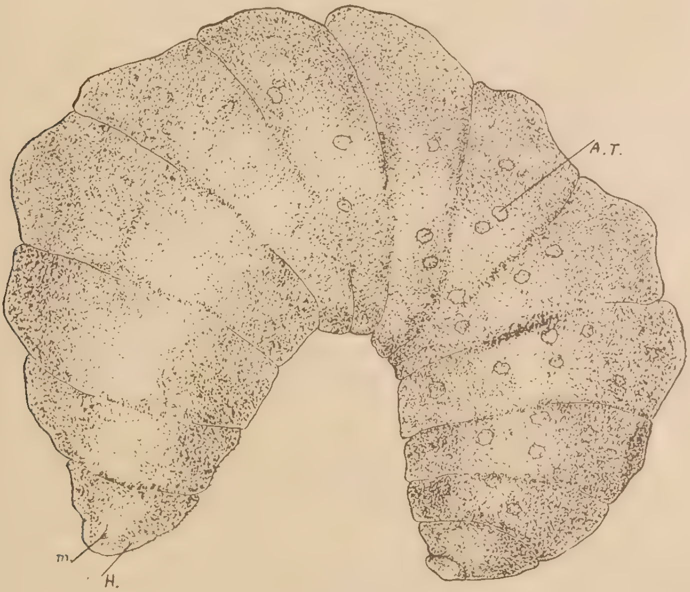

Fig. 4. Mature larva of *A. granarius*, Marsh.: H., head; m., mandible; A.T., adipose tissue.

The mature larva (fig. 4) is pale green in colour, apodous, soft, covered with a secretion and possessing a number of irregularly shaped structures (A.T.) under the cuticle in the posterior region of the abdomen. These have been referred to by Wheeler (1923) in *Aphidius phorodontis*, Fitch, as probably groups of adipose tissue, and by Thompson (1930) in *Eulimneria crassifemur*, Thoms., as urate cells. The larva is composed of 13 segments, widest in the mid region, tapering to the anterior and posterior extremities, with the terminal segment more rounded than the head. The dorsum is thickly beset with spines which are absent towards the ventrum, except on the head and prothorax.

The alimentary canal (fig. 5, A.c.) in the mature larva is relatively large and straight, narrowing anteriorly to form the oesophagus (Oe) in the second thoracic segment and posteriorly in the tenth segment to form the hind gut. Differentiation into ileum (Il) and rectum (Re) is apparent in the hind gut, but in the third-stage larva this is not so. In the first and second stages the alimentary canal is represented by a closed sac (cl.s.). Salivary glands first appear in the second-instar larva, where they are present as two small straight tubes lying over the gut. Increase in size in these structures ensues until in the mature larva they are large and much convoluted, fusing anteriorly to a single duct (S.d.) opening to an orifice on the labium. The respiratory system (fig. 6) is represented by two main longitudinal trunks (L.T.) united to one another by an anterior arched loop (a.a.l.) located slightly forward to the first stigmatic branch, while well developed branches supply the spiracles and musculature.

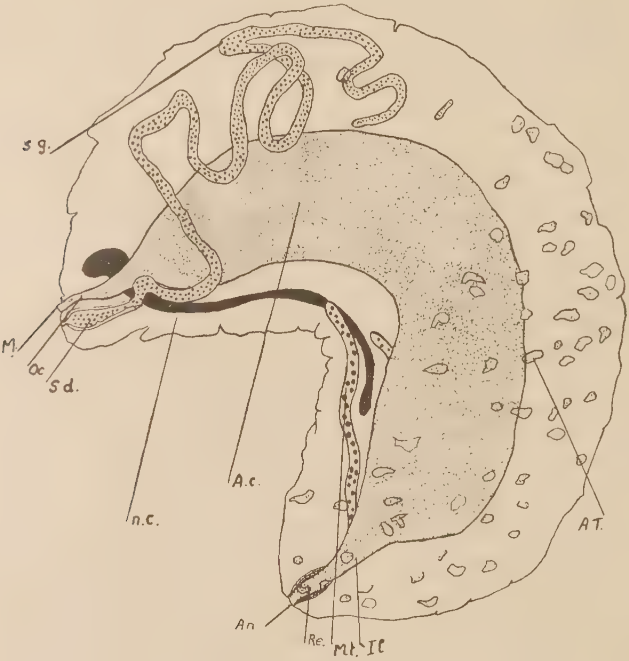

Fig. 5. Internal anatomy of mature larva of *A. granarius*, Marsh.: s.g., salivary gland; M., mouth; Oe., oesophagus; S.d., salivary duct; n.c., nerve cord; A.c., alimentary canal; An., anus; Re., rectum; Mt., Malpighian tubules; Il., ileum; A.T., adipose tissue.

Under outdoor conditions in the summer months, the time between oviposition and the moribund stage of the host varied from 13 to 34 days. During this period the larva makes continuous preparation for pupation and eventually the host becomes sessile. Fluctuations in temperature and humidity appear to be the main factors involved in determining the differences in the length of this period. This variation is indicated in Table II, where the duration of parasitic life from the sessile stage to the emergence of the imago under different conditions is given.

Having plastered the wall of the host with silky threads, the larva becomes less active and passes excreta. This is the first indication of the prepupal stage. It becomes slightly more arched than the mature larva with the terminal segment more

TABLE II.

Conditions of experiment	No. of cases investigated	Temp. °F.		Relative Humidity		Sessile life in days
		Max.	Min.	Max.	Min.	
1. Laboratory	74	67	64	72	54	4–7
2. Insectary	83	75	54	84	60	6–12
3. Out-of-doors	127	75	33	98	71	20–31

pointed, but retains the green colouration of the previous stage. The imaginal discs of the legs and wings are well developed, but they do not appear outside the body. The red imaginal compound eyes are prominent beneath the cuticle and the exuvia (Ex.) of the previous larval stadium encloses the whole body (fig. 7). At 60°F. transformation to the pupa takes place within 4–7 days, and at 70°F. within 4–5 days.

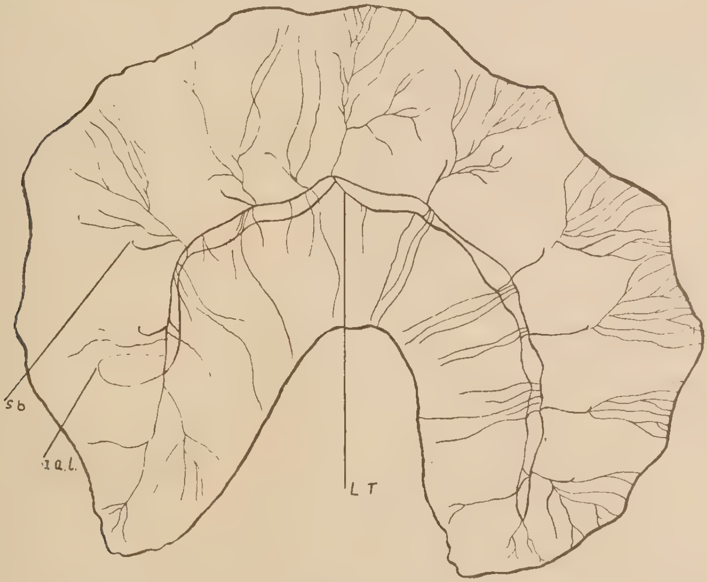

Fig. 6. Tracheal system of mature larva: s.b., stigmatic branch; a.a.l., anterior arched loop; L.T., longitudinal trunks.

Immediately after pupation the pupa is very pale green, and no black markings are discernible. For some time after the pupal moult, the pupa is sticky to the touch owing to the moulting fluid, and there are frequent movements of the abdomen. The new pupal integument is very soft and flexible, but the general conformation of the chief sclerites of the adult can be seen. The pedicel is marked by a slight constriction and segmentation of the abdomen is very faint.

Ventral to the insertion of the antennae are the rudiments of the labium. Below the latter lie the rudiments of the mandibles followed by the maxillae and labial palps. The legs are flexed and glued close against the side of the body, and the antennae, directed posteriorly close to the sides of the body, are conspicuously bent forward about midway along their length. The mesothoracic wing cases adhere to the sides of the body and cover the metathoracic wings.

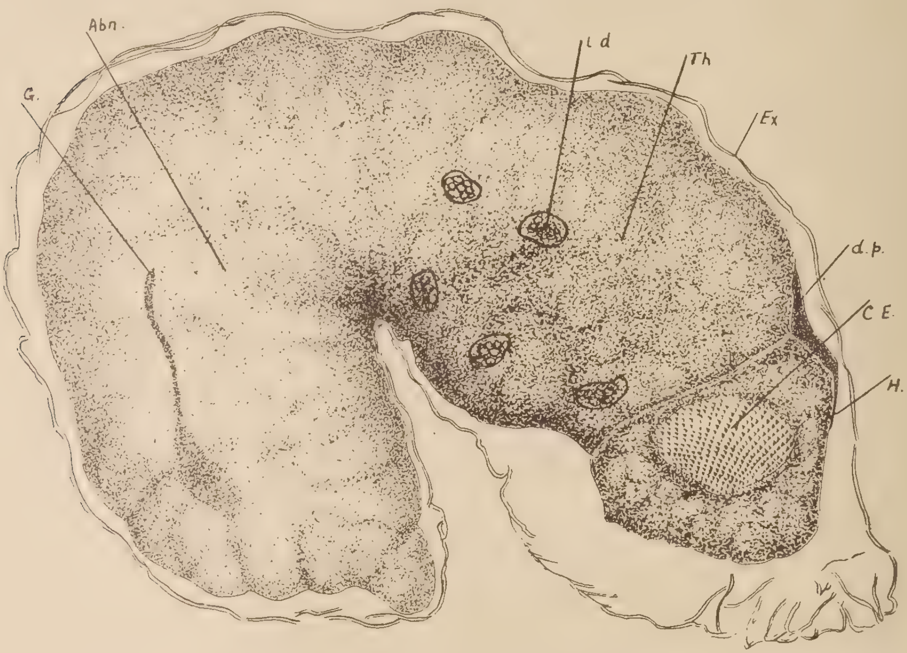

Fig. 7. Prepupa of *A. granarius*, Marsh.: G., gut; Abn., abdomen; i.d., imaginal discs; Th., thorax; Ex., exuvia; d.p., dorsal plate; C.E., compound eye; H., head.

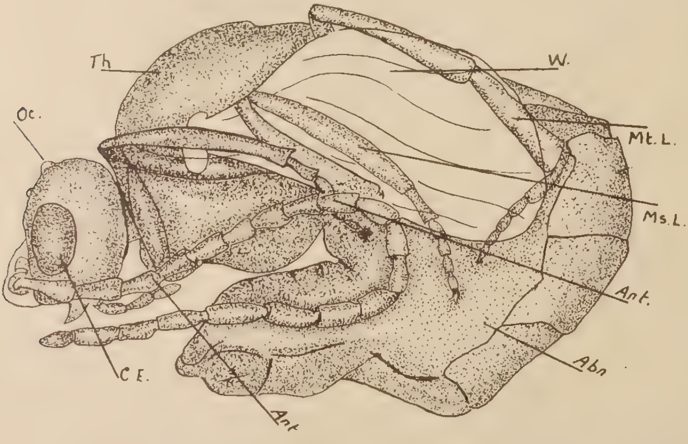

Fig. 8. Pupa of *A. granarius*, Marsh., in the late stages: Oc., ocellus; Th., thorax; W., pupal wing sheath; Mt.L., metathoracic leg; Ms.L., mesothoracic leg; Ant., antenna; Abn., abdomen; C.E., compound eye.

When about two days old, the pedicel is more strongly defined, the cuticle becomes harder and three ocelli appear. Intensification of the colour takes place in the mouth region, and soon afterwards a dark brown pigment is deposited in the mandibles, compound eyes and in the inter-segmental region of the abdomen. This darkening process continues until the pupa is well advanced (fig. 8) and the colour is dark brown. Straightening of the abdomen in relation to the thorax takes place some minutes prior to the transformation to the adult.

Biological Factors influencing the Effectiveness of the Parasite.

(i) *The Rate of Multiplication of the Parasite.*—The very high numbers of parasitised Aphids recovered from the field suggest that the rate of reproduction of the individual parasite is high. This was tested under laboratory conditions by liberating mated and unmated females of the parasite under glass chimneys containing 20 adult apterae of *Myzus kaltenbachi.* The total progeny of 23 mated (and subsequently proved to be fertilised) females was 1,886 imagines, with an individual minimum of 39 and an individual maximum of 89 from one female. From 10 unmated females the number of descendants was 624, with the lowest and highest from one parent of 25 and 73 respectively. The progeny of both series completed their life history within 18 to 23 days. Typical results from both series of experiments are presented in the following Table :—

TABLE III.

Series 1. *The number of potential imagines of* Aphidius granarius *obtained from single fertilised females.*

Cage No.	After a period of	Sessiles obtained	Imagines obtained	Apparently unparasitised Aphids
1	38 days	84	83	7
2	38 ,,	39	39	3
3	38 ,,	75	71	12
4	35 ,,	89	84	0
5 (control)	38 ,,	0	0	2,081

Series 2. *The number of potential imagines (male) of* Aphidius granarius *obtained from single unmated females.*

6	38 days	32	31	12
7	38 ,,	73	73	14
8	38 ,,	61	61	17
9	38 ,,	25	25	23
10 (control)	38 ,,	0	0	1,552

Favourable development of the Aphid occurred in the early stages prior to the introduction of the parasite, but with the liberation of the latter, the survival potential of the Aphid was seriously affected, resulting after 38 days in a 92·9 per cent. parasitism of the Aphid population (parents and descendants) in Series 1, and 86·5 per cent. in Series 2.

(ii) *Sex Ratio.*—From several hundred Aphids, parasitised by fertilised female parasites within two days of mating, and bred out under glass chimneys in the laboratory, there emerged 473 females and 366 males, that is, about 12·9 : 10 ratio. The product of unfertilised females was, however, exclusively male, which when mated with females produced progeny in the above specified ratio.

(iii) *Longevity of the adult Parasite.*—At temperatures of 45°F. and supplied with an abundance of Aphids, 120 adult parasites survived for 17–25 days. Under similar conditions at room temperature the longevity period fluctuated from 7–40 days.

Unfed individuals rarely survived for more than seven days, but by feeding on weak carbohydrate solutions the length of life was increased by 3–15 days.

The frequency with which *A. granarius* adults visited flowers was extremely low, members of the Compositae proving least attractive and members of the Leguminosae most so. Often in the laboratory in the absence of any alternative food material and after a four-day starvation period, the imagines attacked and chewed holes in the bases of the corolla tubes of red clover. In the absence of phanerogams in corn fields from which they were recovered, further investigations on their principal means of sustenance were carried out. It is well known that Aphids are able to imbibe considerable quantities of carbohydrates, which they excrete through the anus. Under the binocular microscope the parasite has been observed to feed voraciously on this excreta and given this sole nutritive material, 153 adults survived for 21–27 days.

(iv) *The Dissemination of the Parasite.*—In view of the effectiveness of parasitism in the field in the control of the Aphid, studies on its dissemination acquired special significance from an economic standpoint. Flight periods of the adult parasites are most prevalent when air temperatures vary from 25° to 30°C., the wind velocity is less than seven miles per hour and the relative humidity is about 70°. When atmospheric humidities are low and the percentage of cloud is high, the flight periods are not as frequent nor as sustained, and they revert to crawling on the underside of leaves where, as Ramsay and others (1938) have shown, the humidity gradient is higher.

Dispersal of the parasite within the limits of a localised zone may also be brought about by the movement of an affected Aphid in the premoribund stages, this being further accentuated by external stimulants inciting more rapid movement. Laboratory experiments also indicate that newly emerged Aphids, whilst susceptible to attack, are not likely to function as effective transmitters of the immature parasites, as in only 19 per cent. of the specimens examined was there any evidence of oviposition, compared with 83 per cent. in the mature apterae. Under similar conditions alate forms are even less subject to attack, and out of 195 alate forms in glass cages only 26 were parasitised. In 5,640 sessile specimens collected in the field a 6 per cent. parasitism of alate forms was recorded.

Hence it appears that, apart from direct flights, the most efficient mode of dispersal is by the localised movement during the premoribund stages of a parasitised, mature, apterous form.

Factors limiting the Effectiveness of the Parasite.

(i) *Thermal Change—Susceptibility.*—There are several generations in one season, and the winter is passed as a mature larva inside the cocoon, the first adults emerging about the middle of March, shortly after the appearance of the Aphid. The susceptibility of the adult Braconid to occasional high temperature spells during the winter months may induce in many years the premature emergence of the parasite, which in the absence of an adequate food supply or suitable hosts and subject to sudden diurnal temperature variations frequently results in death.

(ii) *Oviposition Failure.*—On occasions in the attempts at ovipositing in the Aphid, the adult Braconid comes into contact with the honey-dew excretion, with the result that the ovipositor may be temporarily or permanently incapacitated by blockage. An analysis of 284 Braconids 24 hours after liberation in a cage of Aphids revealed that 4 per cent. failed to lay eggs. Under such conditions egg laying may have to be postponed or even in extreme cases entirely abandoned.

The points of oviposition in the Aphid body, although mainly confined to the abdomen, are a matter of chance. When eggs are laid in the antennae, legs, cornicles, and on occasions in the cauda, no further development takes place. Observations on the location of ovipositing points in 22 specimens of *M. kaltenbachi* are tabulated in Table IV, with some indication of the resulting degree of parasitism effected.

TABLE IV.

The Number of Points of Oviposition in different Parts of the Aphid Body.

Part of the body.	No. of oviposition points	Degree of parasitism*
Head	1	—
Antennae	4	—
Thorax	13	±
Legs	112	—
Abdomen	623	+++
Cornicles	7	—
Cauda	13	±

* + indicates parasitism of 20 per cent. (or multiples) of the Aphids.
± ,, ,, ,, 5 to 10 per cent. of the Aphids.
— ,, ,, ,, less than 5 per cent. of the Aphids.

(iii) *Supernumerary Larvae.*—The adults may lay eggs on more than one occasion in the individual Aphid, and as only one larva attains maturity, the surplus larvae are either killed or die. The cause of death in other parasitic Hymenoptera has received the attention of many workers. Timberlake (1910), Spencer (1926) and Wheeler (1923) suggest it to be primarily of a biochemical nature, while Vevai (1942), Thompson & Parker (1930) believe some measure of cannibalism to take place. The present work confirms the results of the latter workers, as the dissection of 41 mature larval guts revealed in five specimens, three mandibles of the third-stage larva and four mandibles of the first-stage larva. However, as pointed out by Vevai (1942) it is unlikely, though not impossible, that a larva may ingest its own moult. The same writer, quoting Thorpe, considers that the heavily sclerotised mandibles of the first and second stages of *A. matricariae*, Hal., suggests predatory habits.

(iv) *Meteorological Conditions.*—Climate appears to be one of the important factors restricting the flight activities of the parasite, which is more affected by low temperatures than its host. In the months of April 1942 and 1943, when the temperatures ranged from 52°F. to 64°F., the growth of the parasite population was slow, but, with the onset of temperatures ranging from 64°F. to 72°F., the rate of parasitism was considerably accelerated. During wet periods the Aphids and parasites are confined to the underside of the leaf; such conditions are conducive to mating of the parasites and also for oviposition, but under such circumstances effective dissemination of the immature stages is very limited.

Degree of Control in the Field.

Aphids parasitised in the first two instars do not reach maturity, those parasitised before the end of the third instar reach the adult stage but are unable to reproduce, while the number of young produced by those attacked later is very considerably reduced. In view of the results obtained from laboratory experiments the percentage parasitism in the field was determined. For this purpose sets of plants were collected in the following manner :—The field was divided into two halves, in each of which ten points were selected 30 feet apart in a zig-zag pattern, and at each point 20 plants were removed into stout paper bags, the ends of which were fixed with adhesive tape. The numbering and identification of the bred-out parasites were carried out in the laboratory and the results are indicated in Table V.

In the field the parasite first made its appearance in large numbers in mid-April, increasing in intensity until the beginning of June when the high level of parasitism remained constant until the end of July, at which time the number of unaffected Aphids is negligible. This may be due to either the effectiveness of the Braconid in its control or else a migration of the host to alternative food-plants.

TABLE V.

The number oj parasitised ***Aphids*** *recovered from five affected oat-fields in South Wales. (The following data refer to* A. granarius, *which were identified after breeding out and compared with type specimens of this species.)*

Centre	Crop		Degree of Control								
Village Farm, Penhow	Winter Oats	Date ...	23.5.42	30.5.42	8.6.42						
		Actual No. Parasitised...	279	199	285						
		% Control	75	80	95						
Llwynygrant Farm, Cardiff	Spring Oats	Date ...	15.4.43	27.4.43	2.5.43	5.5.43	12.5.43	16.5.43	21.5.43	26.5.43	29.5.43
		Actual No. Parasitised...	39	43	76	285	425	421	464	392	487
		% Control	10	12	30	33	38	59	67	68	76
Llwynygrant Farm, Cardiff	Winter Oats	Actual No. Parasitised...	27	46	39	58	76	284	298	385	521
		% Control ...	11	14	20	41	54	60	77	83	85
Llwynygrant Farm, Cardiff	Winter Oats	Actual No. Parasitised...	32	85	93	76	98	129	163	178	204
		% Control ...	7	20	27	35	44	79	86	87	90
Land at Whitson	Winter Oats	Actual No. Parasitised...	31	42	67	121	231	325	343	392	412
		% Control ...	2	13	22	25	47	—	73	—	94

While the Aphids remain on the oats, the conditions for the reproduction of *Aphidius* are favourable, but when once migration occurs, the parasites emerging from the cocoons that remain behind must search for new hosts, while those transported by the alate forms in the immature stages must necessarily have but a limited supply of fresh ovipositing material when they mature.

The occurrence of the parasite in the field does exercise some measure of control on the Aphid in the early part of the year, when plant tissues are young and succulent and Aphid attacks would have most serious consequences. Nevertheless, as pointed out by Ullyett (1938) for the genus *Aphidius*, the respective rates of reproduction of parasite and host and the possibility of reduced reproduction by parasitised Aphids implies that *A. granarius* is unable to cause an appreciable reduction of the Aphid population until the latter has passed through several generations, and that the effectiveness of parasitism in the fields examined is not apparent until about the middle of May, when over some 50 per cent. of the Aphids are parasitised.

Summary.

1. *Aphidius granarius* is an internal parasite of *Myzus kaltenbachi*, where the latter is found infesting corn crops in South Wales.

2. The emergence of the adult parasite is described. Mating takes place within two hours of emergence, the females may be mated with more than one male.

3. A brief description of the morphology of the egg, larval, prepupal and pupal stages is given.

4. The rate of reproduction of the females of *A. granarius* is high, with female : male as 12·9 : 10. Unmated females always produce males.

5. The adult parasite under normal conditions lives for 21–27 days and flies readily under favourable meteorological conditions. Within limited areas dissemination may be brought about most effectively by mature parasitised apterae.

6. The factors limiting the effectiveness of the parasite are briefly described. The degree of control at the end of May in the field may approximate to 90 per cent.

Acknowledgments.

I wish to express my sincere gratitude to Dr. E. E. Edwards, who supervised the work, for his encouragement and ready aid in the prosecution of this enquiry. I should also like to express my sincere appreciation of the helpful criticism and advice received from Prof. R. Douglas Laurie, Mr. C. T. Gimingham, Miss K. L. Pears and Mr. L. Cowley.

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THE INFLUENCE OF RAINFALL, TIDES AND PERIODIC FLUCTUATIONS ON A POPULATION OF *ANOPHELES MELAS*, THEO.

By Major C. R. Ribbands, R.A.M.C.

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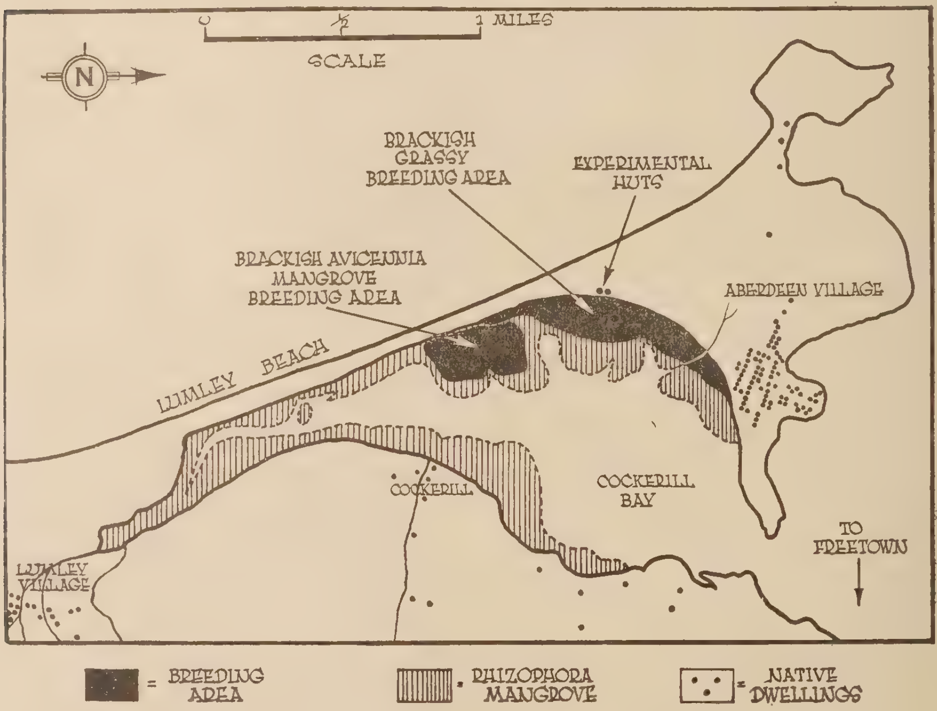
Introduction.

Anopheles gambiae var. *melas* was first described by Theobald (1903), and at the same time Dutton (1903) recorded the breeding of *A. gambiae* in seawater. These two observations were not correlated, but most later workers have believed, with Evans (1931), that the melanic pigmentation of the variety was a direct and temporary response to brackish environmental conditions. They have therefore made no effort to distinguish between the two forms.

Permanent structural and physiological differences between these two forms have recently been discovered (Ribbands 1944), and in consequence it is now clear that *A. melas* is a separate, though closely related, species. Correlated with this distinction has been the recognition of the fact that *A. melas* is the most important malaria carrier in many parts of the coastal region of West Africa, which abounds in brackish mangrove swamps and lagoons. The following observations on the habits of this species were made during 1941 at Aberdeen, near Freetown, Sierra Leone, in a typical brackish water breeding area. They are compared with a smaller series of observations on *A. funestus*, which were made near Sekondi, Gold Coast, in 1942.

THE EXPERIMENTAL AREA AND POPULATION.

Aberdeen is a small peninsula, five miles west of Freetown, Sierra Leone. The rainfall in 1941 was 137·6 inches. This fell mainly in the wet season, which lasts from June to September, inclusive, but some rain fell in May and between October and early January. In July and August rain falls during both night and day, but in other months it usually comes in night storms. Details of the rainfall, from data obtained from the Meteorological Office, Freetown, are given later. The temperature range is slight, varying between 72°C. and 85°C. in the wet season and 80°C. and 95°C. in the dry season. Wet season humidities are about 90 per cent., and dry season about 70 per cent. R.H. Variation is small during both.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N
BRACKISH GRASSY BREEDING AREA
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BRACKISH AVICENNIA MANGROVE BREEDING AREA
ABERDEEN VILLAGE
LUMLEY BEACH
COCKERILL
COCKERILL BAY
TO FREETOWN
LUMLEY VILLAGE
= BREEDING AREA
= RHIZOPHORA MANGROVE
= NATIVE DWELLINGS

Fig. 1.—Aberdeen and District.

The accompanying map (fig. 1) indicates the more important characteristics of the Aberdeen district. The end of the peninsula is composed mainly of laterite rock, rising to 50 feet. It was originally an island, but has become connected to the mainland by a long and permanent sand-bar which stretches to Lumley. This sand-bar has cut off the seaward outlet of several large streams all of which now enter Aberdeen Creek. These streams have brought down a rich alluvium which has been deposited on the edges of the creek, nearly all at the Lumley end and on the Aberdeen side.

This laterite alluvium has been combined in varying proportions with sand to form a large, even and gently-sloping tidal flat. Two parts of this area are of great malarial importance. The first of these is a grass covered area, nearly one mile long and up to 200 yards broad, close to Aberdeen. This region is flooded by the highest tides only. In the wet season it is always boggy, but during the dry season, it is mainly dry at neap tides. Breeding was found to be prolific in this area. The second is situated between Aberdeen and Lumley, and is covered with *Avicennia* mangrove. Investigations by Dr. Muirhead Thompson, now in progress, have shown that this area also is a prolific source of *Anopheles*. The remainder of the flat area is covered with *Rhizophora* mangrove and is of relatively little malarial importance.

Only one purely freshwater *A. gambiae* breeding area existed on Aberdeen peninsula. This was the swampy stream which flowed into Aberdeen Creek west of Aberdeen village. It was drained by Mr. Slater in December 1940, and since that time the very large Anopheline population of Aberdeen has arisen from the two tidal areas just described.

In the dry season all the standing water on these areas is saline, and the mosquito population must be almost entirely *A. melas*, but in the wet season, and especially at neap tides, along the upper edge of the grassy breeding area there are parts where there is standing and seepage water which is fresh or almost fresh, and capable of supporting a population of *A. gambiae*.

Unfortunately no certain way of distinguishing all adult *A. melas* from *A. gambiae* has been found, but it is known that a variable proportion of *A. melas* are distinguished from *A. gambiae* by the presence of extra dark pigment of the maxillary palps (Ribbands, 1944). This black pigment either bisects or partially bisects the terminal white band of the palp. Specimens with this extra dark pigment may be conveniently designated "*melas*-banded."

Analysis of the mosquitos caught in the experimental huts shows that the percentage which were "*melas*-banded" was : January, 34 per cent. ; February, 34 per cent. ; March, 29 per cent. ; April, 40 per cent. ; May, 52 per cent. ; August, 30 per cent. ; September, 33 per cent. I know that some *A. gambiae* were present in the early rains, and it is to be regretted that this record is incomplete. The existing portions, however, do indicate that the proportion of *A. melas* in the population was not very different in the latter half of the rainy season from what it was in the dry season when I believe that the population consisted almost entirely of *A. melas*. For these reasons I consider that the experimental population dealt with in this paper can be considered, for practical purposes, to have consisted of *A. melas*.

METHODS OF COLLECTION.

Two shimbecs were constructed in January 1941, close to the grassy breeding area, and 440 yards from the nearest native dwellings, which were in Aberdeen village. These shimbecs were built of raffia palm, on a framework of bushsticks, and they were lined with straw-coloured native rush matting which provided a suitable but impenetrable resting surface for mosquitos. Each hut was 10 feet by 6 feet, and 6 feet high at the eaves, and provided with an opening near one end, coverable by a door of loosely-woven raffia palm.

In August more huts were erected close by, similarly lined but covered with flattened oil drums instead of raffia palm, so that they were more rainproof. The two original huts were similarly re-covered.

The same two natives were employed throughout the experiments, and from 2nd August onwards two additional ones were also employed. Each native slept in a separate hut, and the catch from each hut was recorded separately. The room index for any one day was obtained by taking the total number of mosquitos caught and dividing this figure by the number of natives (two from January to 1st August, four from 2nd August onwards) used as bait. Certain other experiments, to be described elsewhere, were carried out simultaneously, but only one of these affected the results in any way—this experiment lasted from 30th July until 26th August, and reduced the average catch of one of the natives by 27 per cent., a difference that has been compensated for in the results now published.

The mosquitos were always caught by the spray method, except during the period between 18th February and 8th May when, in addition, a preliminary hand-catch was made before the spraying took place. In each case the floor of the hut was covered with sheets, and the door closed. The room was then flitted, using a hand pump and a pyrethrum-in-kerosene spraying mixture. The sheets were carefully carried into the open and the dead mosquitos collected from them. This method is, in my opinion, very much more accurate as well as simpler than hand-catching. Without entering into details of its efficiency, the results which follow, and which show that it is sufficiently accurate to demonstrate small weekly fluctuations in mosquito numbers, and to enable logical deductions to be drawn from them, are a good demonstration of its merit.

Short-Term Fluctuations in the Population.

1. Fluctuations in the Population Size.

Using the methods outlined above, a daily room index was obtained for the period from 10th January to 31st October, 1941. The few male Anophelines were not included in the index. This daily index, when graphed, showed many small random fluctuations, which tended to obscure the larger and more significant variations, and it was found that these random fluctuations—a necessary corollary of the small size of the sample and of variation in day-to-day conditions—could be ironed out by plotting, for each day, an average room index for three days—the day itself, the preceding day and the following day.

The accompanying graphs (figs. 2 and 3) show this three-day average room index for the whole period, together with the daily rainfall for this period (from statistics compiled for Freetown by the Meteorological Office, Freetown) and the estimated height of maximum high water for each day (taken from " Tide Tables," Sierra Leone, 1941, published by the Government Printer, Freetown).

Examination of these shows that there are definite peaks in it at variable but well-defined intervals throughout its course. Some standard must be defined to assess which of these peaks are large enough to be significant, and the standard which I have arbitrarily adopted is that such a peak must show an increase of at least 30 per cent. over the lowest three-day average of the minimum immediately before it, and must be followed by a drop in the three-day average of at least 20 per cent. Such a standard probably does not disclose all the peaks in the population, and they are especially likely to be obscured at times of continual and rapid increase or decrease, but a glance at figs. 2 and 3 shows that the 29 peaks which conform to this standard together comprise nearly all the major variations in the curve.

Table I shows the date of each peak, the amount of increase of each peak over the previous minimum, and the decrease after each peak, together with the number of days between successive peaks.

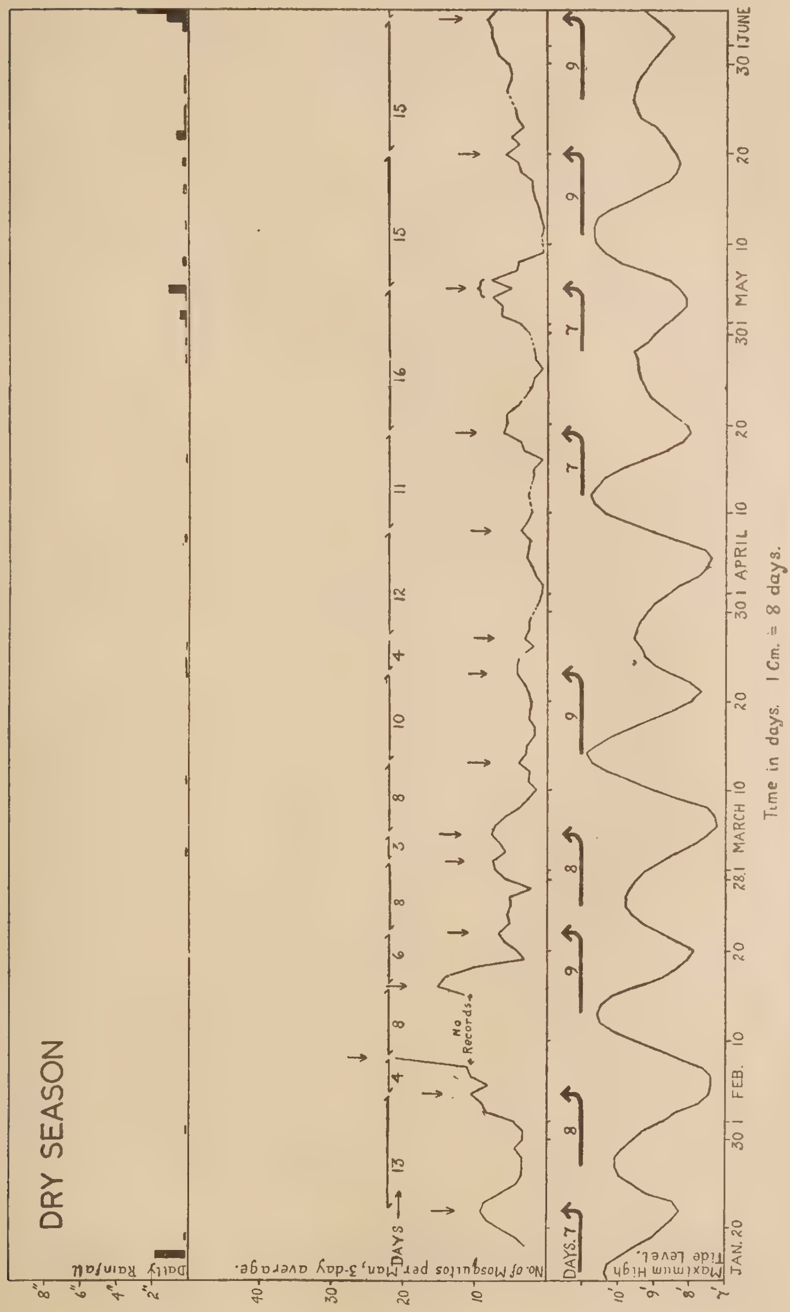

Fig. 2.—Effect of rain, tides and periodic fluctuations on mosquito numbers in the dry season.

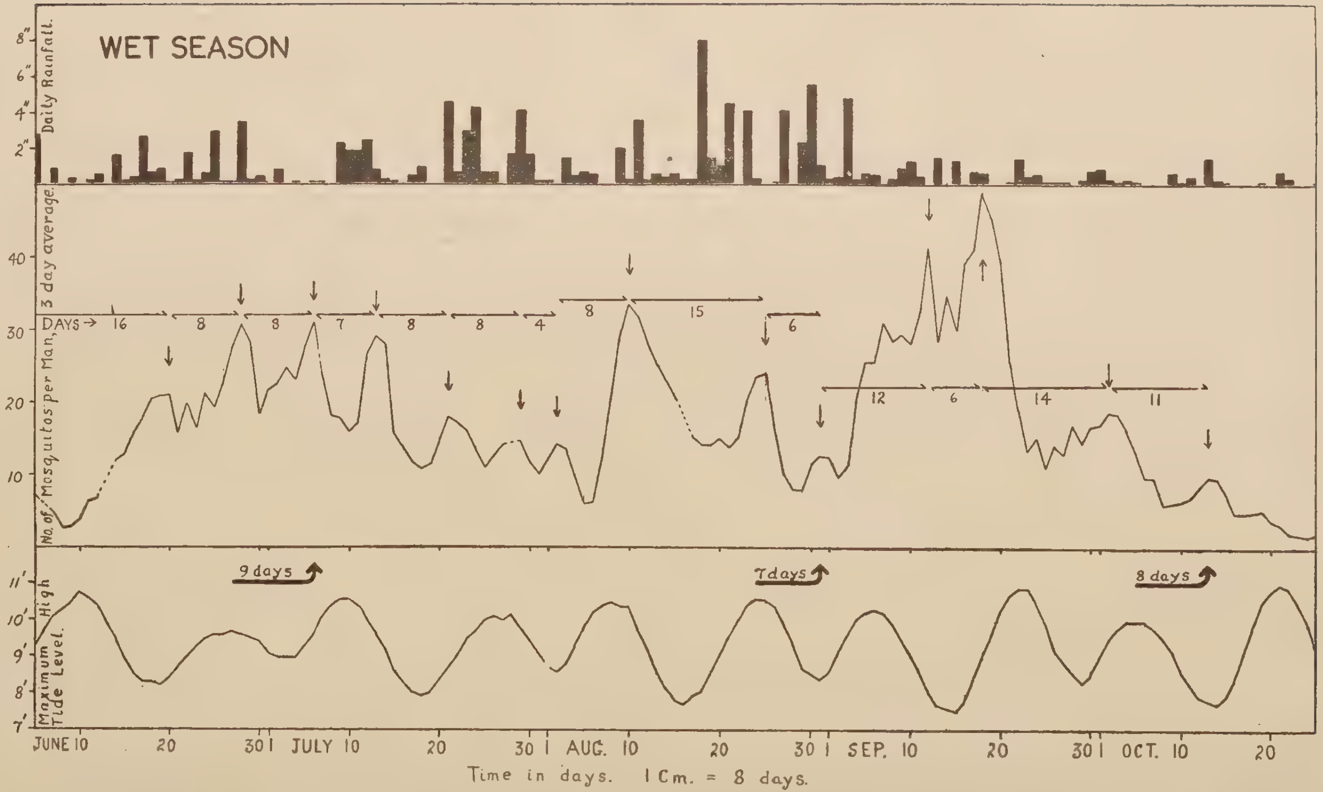

Fig. 3.—Effect of rain, tides and periodic fluctuations on mosquito numbers in the wet season.

2. Amplitude of the Fluctuations.

Table I shows that there is wide variation in the amplitude of the fluctuations, so that any concept of an average amplitude throughout the whole period would be misleading. In the nine peaks of January, February and March (but excluding the peak of tidal origin on 5th March, which follows very closely on the peak due to periodic fluctuation on 2nd March), the minimum increase that occurs between any peak and the previous minimum is 110 per cent., and the maximum is 245 per cent.—the average increase is 175 per cent., and there is no significant difference in amplitude between those peaks associated with increases due to rainfall and the others. In April and May the amplitude is greatly increased, with a minimum increase of 430 per cent., a maximum of 1060 per cent., and an average of 820 per cent. Then wet season conditions begin to operate, and the amplitude decreases ; on four occasions thereafter large increases due to heavy rain cause the peak population to be more than 100 per cent. above that of the previous minimum, with a maximum increase of 710 per cent. for the 20th June peak, but the amplitude is otherwise much smaller —on occasions where the population remains fairly stable it varies between peak increases of 40 per cent. and 85 per cent. over minima.

The amplitude of the short-term fluctuations is thus much greater in the dry season than in the wet, and greatest towards the end of the dry season, when the size of the population is minimal. The four periods in April and May, when the population was very low and the minima fairly constant (0·65), and the amplitude average 820 per cent. of minimum, can be compared with three wet season periods, 21st and 29th July and 2nd August, when the minima were again fairly constant (10·7) and the amplitude averaged 45 per cent. of minimum.

The causes of the reduced amplitude in the wet season fluctuations are probably :—

(*a*) The lack of any single dominant factor to determine a main rhythm (*cf.* tides, in the dry season) ;

(*b*) The increased size of the breeding area, in consequence of which it is more heterogeneous, and different parts will tend to have different breeding rhythms, thereby obscuring the main rhythm ;

(*c*) The main rhythm is more frequently upset by irregular climatic changes which tend to induce subsidiary rhythms ;

(*d*) The climate is more conducive to longevity in the adult mosquito, so that peaks due to new breeding are less obvious ;

(*e*) The period of the wet season fluctuation is usually only one-half that of the dry season fluctuation (this factor only accounts for a small part of the difference, as can be seen by examining, in Table I, the amplitude of the exceptional long dry season and short wet season periods).

3. Relation between Population Size and Rate of Adult Emergence.

All the catches recorded were samples of the adult population, and a peak in the adult population does not necessarily mean that the maximum emergence of new adults occurred on this day. Fig. 4 illustrates the relation between the date of the maximum adult population and the date of the maximum emergence of new adults in the simplest possible theoretical conditions, and shows that when the rate of adult emergence is randomly distributed about a maximum and the life of each emergent is three days, the maximum population is obtained one day after the maximum number of new emergences ; if the life is increased to five days, the maximum population is obtained three days after the maximum number of new emergences, and each further increase in life of two days means an additional delay of one day between the peaks of population and of new emergences.

TABLE I.

Schedule of Fluctuation Peaks.

Date of Peak	22/i	4/ii	8/ii	16/ii	22/ii	2/iii	5/iii	13/iii	23/iii	27/iii	8/iv	19/iv	5/v	20/v	4/vi
3-day average at peak	9·3	10·6	21·2	15·2	6·8	7·6	7·8	4·0	4·2	3·2	3·7	6·2	7·7	5·8	8·3
3-day average at inter-peak minimum	3·0	3·3	8·2		3·2	2·2	5·8	1·6	1·8	2·0	0·7	0·7	0·7	0·5	3·3
Peak increase over previous minimum	210%	220%	160%		110%	245%	35%	150%	135%	60%	430%	785%	1000%	1060%	150%
Decrease after peak	67%	23%		79%	68%	24%	79%	55%	52%	78%	81%	89%	94%	43%	69%
Number of days between peaks		13	4	8	6	8	3	8	10	4	12	11	16	15	15

TABLE I.—*Continued.*

Date of Peak	20/vi	28/vi	6/vii	13/vii	21/vii	29/vii	2/viii	10/viii	25/viii	31/viii	12/ix	18/ix	2/x	13/x
3-day average at peak	21·0	30·7	31·2	29·2	18·0	14·8	14·3	33·5	24·0	12·5	41·2	49·0	18·6	9·8
3-day average at inter-peak minimum	2·6	15·8	18·3	16·0	10·8	11·2	10·2	6·0	13·8	7·8	9·5	28·5	11·3	6·0
Peak increase over previous minimum	710%	95%	70%	85%	65%	30%	40%	460%	75%	60%	335%	70%	65%	60%
Decrease after peak	25%	40%	49%	63%	38%	31%	58%	59%	68%	24%	31%	77%	68%	
Number of days between peaks	16	8	8	7	8	8	4	8	15	6	12	6	14	11

These theoretical conditions do not occur in nature, but although the relationship is more complicated, it is not substantially different. Skewing of the rate of adult emergence or substitution of an average length of adult life for a fixed length of life will seldom alter the general conclusion drawn, and it may be considered that if the average adult life is three days, the usual time-lag between maximum emergences and maximum adult population is one day, and each additional increase in the average length of adult life of two days will increase the time-lag by an additional day. A more important factor, which might substantially reduce the time-lag in practice, is that it cannot be proved that the adult catches were in fact true samples of the adult population—as they were obtained close to the breeding ground, they may have contained a larger proportion of the new emergents, and this factor might reduce or eliminate the calculated time-lag.

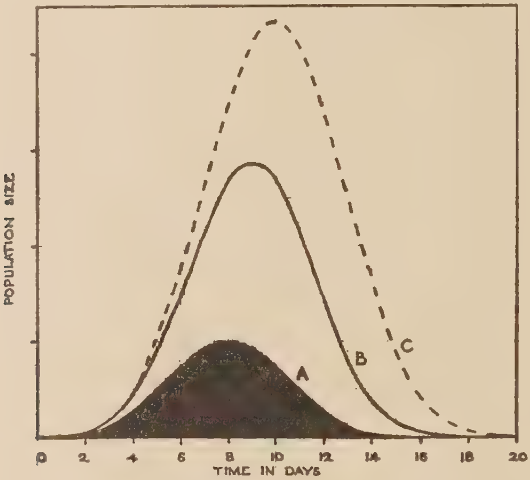

Fig. 4.—Theoretical relation between rate of emergence, longevity and population size. A : Number of new emergences. B : Size of population if each adult lives exactly three days. C : Size of population if each adult lives exactly five days.

This potential time-lag between the emergence maximum and the population maximum affects deductions which may be drawn concerning the effects of the tide on the population, but not the calculations concerning the frequency of the periodic fluctuations (where the lag will be similar at both peaks), and it cannot be of much consequence in deductions concerning rainfall where the effects on the population are so long delayed that a variation of a day or two makes no marked difference to the conclusions drawn.

4. Influence of Tides on the Population.

Table II gives the dates of the 19 spring tides that occur between 10th January and 20th October (full details of the daily maximum high tide level are given in figs. 2 and 3) and shows the number of days after spring tide at which occur each of the 29 peaks enumerated in Table I. After each spring tide there are one, two or three peaks. Fig. 5 records the number of days after spring tide at which each peak occurs.

(a) *Dry Season Conditions.*

Examination of figs. 2 and 3 shows that 15 peaks occur in dry season conditions (between 10th January and 5th June) and that 9 of these 15 peaks occur either

TABLE II.

Relation between maximum tides and maximum mosquito numbers.

DRY SEASON

Date of maximum tide	15/i	27/i	13/ii	25/ii	14/iii
Interval, in days, before mosquito peaks	7	8 and 12	3 and 9	5, 8 and 16	9 and 13
Date of maximum tide	27/iii	12/iv	28/iv	11/v	26/v
Interval, in days, before mosquito peaks	12	7	7	9	9

WET SEASON

Date of maximum tide	10/vi	27/vi	9/vii	28/vii	8/viii
Interval, in days, before mosquito peaks	10	1 and 9	4 and 12	1 and 5	2
Date of maximum tide	24/viii	6/ix	22/ix	5/x	21/x
Interval, in days, before mosquito peaks	1 and 7	6 and 12	10	8	—

seven, eight or nine days after a spring tide. The other six all occur either four, eight or 12 days after a previous peak and are due to periodic fluctuations (as will be shown later) but the peaks associated with the tides usually bear no relation to the 4-day period, and occur after 13, 6, 3, 10, 11, 16, 15 and 15-day intervals respectively.

During this period there are 10 spring tides, and nine of these are followed by a mosquito peak at a 7–9-day interval (see fig. 5). In this period there are 138 days, and 30 of these occur in the 7 9-day post-tidal period, so therefore the average chance that a randomly distributed peak will fall within this 7–9-day period is 30÷138, or 0·217. Expansion of the binomial (0·217 + 0·783) shows that the chance of obtaining nine or more peaks at this interval is 0·0015.

Hence it may be concluded that the distribution of peaks in relation to tides differed very considerably from chance, and in dry season conditions maximum numbers of mosquitos usually occurred about eight days after maximum tides.

(*b*) *Wet Season Conditions.*

Fourteen peaks occur in the wet season (6th June to 30th October), and examination of fig. 5 shows that they are fairly randomly distributed irrespective of spring tides—the only marked aggregation which I consider fortuitous, is that three occur on the first day after spring tide. Only three peaks occur in the 7 9-day interval after maximun tides, and one of these occurs at the very end of the season, when dry season conditions begin to return. The mean expectation of peaks within this period is 2·7, and so this result gives no indication of any wet season relationship between spring tides and mosquito peaks.

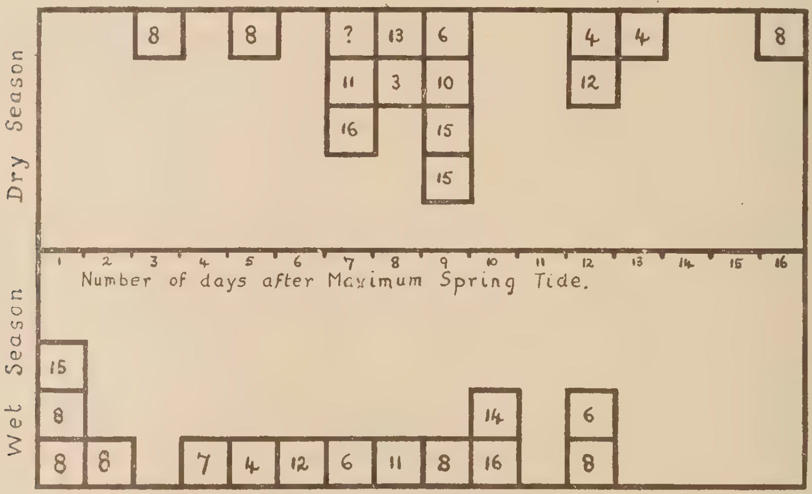

Fig. 5.—Relation between maximum spring tides and population peaks.

(*c*) *Analysis of Correlation Coefficients.*

Correlation coefficients emphasise the conclusions outlined above. Table III shows the correlation coefficients between the daily tidal height and the three-day mosquito average at intervals of five, six, seven, eight, nine and ten days. Values for the period 3rd March to 5th June, a period uninfluenced by rainfall, show a significant correlation between tidal height and the mosquito numbers seven, eight and nine days afterwards, the values being 0·380±0·092, 0·446±0·086, and 0·462±0·084 respectively. Therefore, in the absence of rainfall, tidal height exerts a marked effect on the size of the mosquito population, with a 7–9-day time-lag.

Values for the whole dry period 18th January to 5th June include that part of the dry season affected by the 1·7 inches rainfall on 17th January. Correlation coefficients for this period have lower values, but they still demonstrate a significant correlation between tides and mosquito numbers seven, eight and nine days afterwards, the values being 0·243±0·084, 0·2122±0·085 and 0·182±0·086 respectively. Thus the presence of even a small quantity of rain greatly reduces the importance of tide as a factor in determining the level of the mosquito population.

Values for the wet season period 6th June to 5th October show that there is a negative correlation coefficient between tidal height and the mosquito population seven and eight days later, the values being −0·125±0·091 and −0·104±0·091 respectively. These negative values are not large enough to be significant, but they do demonstrate conclusively that, in the presence of abundant rain, the height of tide does not control the level of the mosquito population in this area.

(*d*) *Interpretation of relation between Tides and Mosquitos.*

In the case of the tidal fluctuations, the average interval between maximum tide and maximum adult catch was eight days, and therefore the maximum rate of emergence of new adults occurred not more than eight days after the maximum tide. But it has been shown above that there is a probable time-lag between maximum emergence and maximum population, this time-lag varying with the average length of adult life, and in this event the maximum rate of emergence probably occurred less than eight days after maximum tide.

When *A. melas* was reared under favourable artificial conditions at the Sir Alfred Jones Laboratory, Freetown, eight days was the minimum time taken between egg-laying and the emergence of the adults. This corresponds with the findings of workers on *A. gambiae, sens. str.*, since Barber and Olinger (1931) found that in Lagos it took seven to eight days from egg to adult, and Mathis (1935) reared it in Dakar in the same time. Mathis also reported that the whole life-cycle, from egg to egg, took about 14 days under laboratory conditions. More recently, in Brazil and at a temperature of about 26°C., Clausey and others (1943) also found that seven days was the minimum period between egg and adult.

Thus, if the aquatic stages take as long as this in nature, the most successful egg-layings occur either at or before maximum tides.

5. Short Period Fluctuations at Regular Intervals.

(*a*) *Presence of fluctuations at regular intervals.*

Fig. 6 illustrates the variation in frequency between the peaks. The upper part shows the frequency distribution of the 11 peaks which are correlated with tide (those which occur 7–9 days after highest tides)—their distribution is clearly random. The lower part shows the frequency distribution of the 17 peaks which are not correlated with tide, and their distribution shows a marked aggregation on the eighth day, and six of the remainder on the fourth, twelfth, or sixteenth day, while only four out of 17 bear no relation to the eight-day interval.

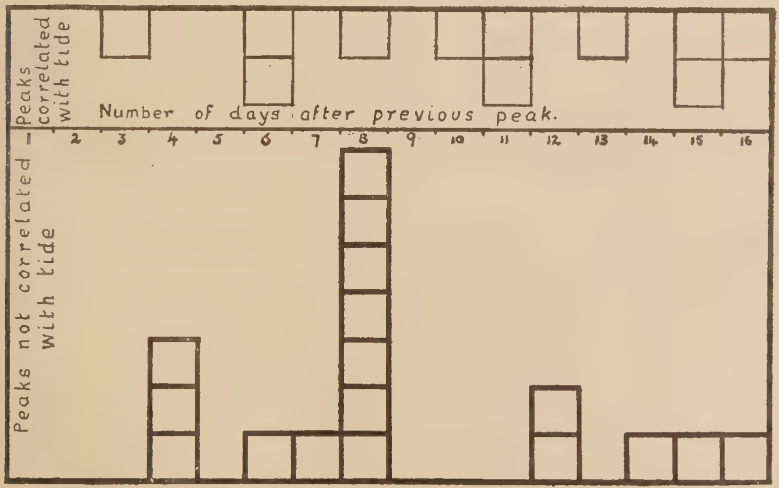

Fig. 6.—Periodicity of the peaks.

Now if these 17 peaks were distributed at random throughout the 16 days, we should expect on any day 17÷15 peaks, or 1·13 peaks per day, so that if there were no bias towards a four, eight, twelve and sixteen-day interval we should expect 4·6 peaks on these days —but actually 13 occurred. Conversely, only four peaks occurred on other days, against an expectation of 12·4. A test of the significance of this distribution yields a χ^2 value of 21·03, with one degree of freedom. The chance that the observed distribution is random is therefore less than 1 in 1,000.

The conclusion drawn from the above result is that, in the absence of tidal effects, there was a marked periodicity in the size of the mosquito population, with maxima at eight-day intervals, and subsidiary peaks at four-day intervals, but that the highest tides frequently obscured this rhythm during the dry season and imposed new peaks at less regular intervals. The rhythm was not disturbed by rainfall, although the aggregate effect of rainfall on the population is much greater than that of tide, because the effects of rainfall are exerted more gradually.

(*b*) *Interpretation of the regular short-period fluctuations.*

The periodic fluctuations raise interesting biological problems. Boyd (1927) showed that the fluctuations in a population of *A. quadrimaculatus* were due to the emergence of successive generations of new adults, each one the offspring of the previous generation, but the eight-day interval between *A. melas* peaks is almost certainly less than that which would be required if these peaks were of similar origin, since the laboratory observations just mentioned indicate that the total aquatic life occupies eight days, the time for complete digestion of a blood meal was found to be at least two days, and the fundamental life-cycle from egg to egg probably takes 12 days or more. I attribute the difference between the fluctuations of these two species to the fact that breeding of *A. quadrimaculatus* is interrupted by winter, and therefore the progeny of the overwintering forms all start from scratch at the beginning of a new season, and there is time for only a few generations before the following winter, when the breeding rhythm is completely restored if it has been upset by external factors. No seasonal factors impose such a rhythm on *A. melas*, and its population fluctuation is therefore more complex.

Lloyd (1941) showed by trap catches of the Chironomid midge, *Spaniotoma minima*, that the rate of adult emergence of this insect showed marked periodicity, with peaks shorter than the life-cycle and caused by the presence at any one time of three broods of different ages, with the offspring of each brood giving rise to a new generation. Lloyd also showed that such peaks and overlapping generations would occur in an originally uniform population as the result of its reaction to varying temperatures, which control the speed of its development. In the case of *A. melas* temperature changes would play little part, but the effects of tide and rainfall might easily cause similar fluctuations.

But comparison shows an important difference between the two fluctuations, for whereas Lloyd demonstrated in *Spaniotoma* a relationship between every fourth brood, because it was the offspring of the first brood, he did not postulate any relation between the timing of the three unrelated broods which were in existence together. In *A. melas* the relationship, if any, between any brood and its parent brood, is obscured by the more conspicuous relationship between each peak and the adjacent peak—successive peaks occurring mainly at four- and 8-day intervals, periods that are too short for a complete generation. The concept of intraspecific competition provides a possible explanation of the regular sequence of peaks, for in laboratory cultures it was usually observed that the development of larvae was very much delayed in the presence of very few larger larvae, owing to competition for the available food supply, and this might also occur in nature in which case these fluctuations would be similar to the fluctuations due to predator-prey relationships, examples of which were calculated mathematically by Volterra

(Chapman, 1931), and which have been shown to occur in experimental cultures by Gauss.

Bates (1941) has tentatively suggested an effect of intraspecific competition in *A. maculipennis*, where he suggested that "the increased percentage of IVth stage larvae in the latter part of the summer may be due to the lower larval population density at this time, which might result in an increased survival rate."

(*c*) *Short-period fluctuations in an* A. funestus *population.*

In conjunction with certain experiments, to be described elsewhere, I was able to conduct a daily sampling of the *A. funestus* population at Krabonekrom, two miles from Sekondi, Gold Coast, between 12th January and 16th March, 1942. The figures given are from daily catches, by spraying, in a single room occupied throughout by the same three natives. This period is in the middle of the dry season at Sekondi, and measurable rain fell only on 11th and 19th January and 13th February; since *A. funestus* was breeding in a freshwater swamp, it could not have been affected by tides.

The catching station was half a mile from the breeding ground, with no intervening houses. The curve of three-day averages (fig. 7) shows four well-marked peaks, at intervals of 12, 14 and 14 days respectively. The numbers involved are large and the amplitude of the fluctuations is considerable, the peaks averaging five and a-half times the size of the minima.

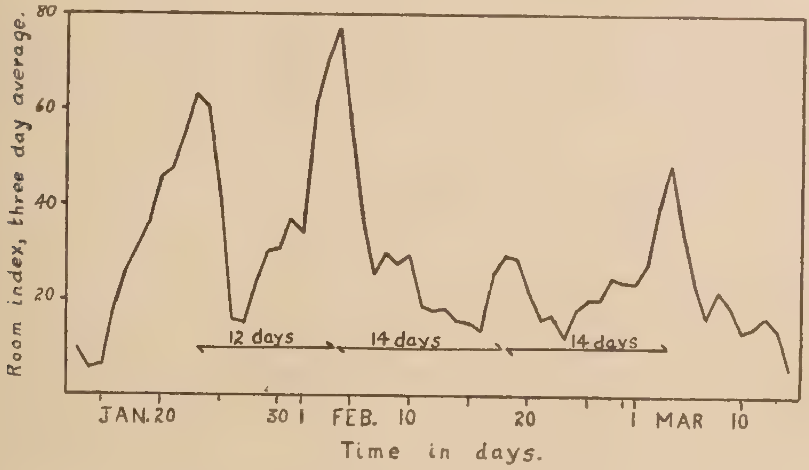

Fig. 7.—Fluctuations in an *A. funestus* population.

Hopkins (quoted by Evans, 1938) states that in Uganda, under field conditions at an average day temperature of 23·4°C., the egg period of *A. funestus* was three days and the larval and pupal periods were 15 and two days respectively, and that in another experiment under field conditions at 26·9°C., the time from egg to adult was 21 days. At the Sir Alfred Jones Laboratory, Freetown, under laboratory conditions at a temperature of about 27°C., I was able to rear *A. funestus* from egg-laying to adult in 16 days. When allowance is made for the time for blood digestion and egg maturation, this evidence indicates that it is unlikely that *A. funestus* could undergo a complete life-cycle, from adult to adult, in 14 days, and it therefore seems that the fluctuations in the *A. funestus* population, like those in the *A. melas* population, are not explicable as a consequence of the emergence of successive filial generations. Thus, in the present state of our knowledge and for want of a more acceptable explanation, they too must be attributed to the effects of intra-specific competition.

Seasonal Variation in the Population.

The effect of the periodic fluctuations, which usually occur at eight-day intervals, can be partially eliminated by grouping the catches, as in fig. 8, which reveals a clear relation between the histogram so compiled and that compiled from the eight-day average for rainfall. When considering this relationship, it must be remembered that the rainfall data were not obtained from Aberdeen itself, but from Freetown, five miles east of Aberdeen. They are therefore not an exact indication of the amount of rain falling on to the breeding grounds, but they are as accurate as the interpretation of the data necessitates. The considerable consequences of the apparently small rainfall on 7th April may have been due to a greater precipitation in the Aberdeen area.

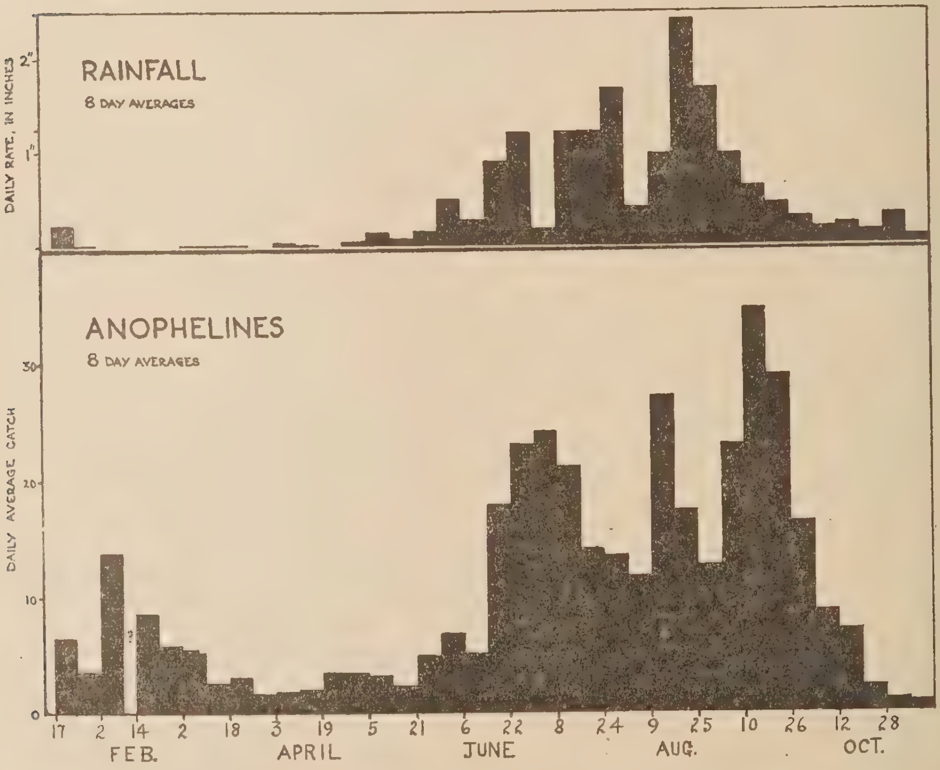

Fig. 8.—Relation between *A. melas* population size and rainfall.

It is best to examine fig. 8, which shows clearly and quantitatively the increase in the mosquito population, and then to examine these same increases in figs. 2 and 3, and compare them with the daily rainfall figures. But before considering the considerable indirect effects of rain on the adult population the possible direct effects must be mentioned.

(*a*) *Direct effect of rain on adult mosquitos.*

The direct killing power of heavy rain on the adult population is slight, or absent. This effect can be estimated by comparing the adult catch two days before the rain with that two days after the rain. This was done for 13 occasions when the daily rainfall exceeded 3 inches, and the average population two days before this heavy rain was 17·7, while two days afterwards it was 15·8, a decrease of 11 per cent. For the 30 occasions (including these 13), when the daily rainfall exceeded 1 inch, the average populations before and after the rain were 19·6 and 19·2 respectively, a decrease of only 2 per cent. Neither of these values are statistically significant, nor are they large enough to be of great practical importance if they were so. Most of the rain fell at night, during flighting time.

(*b*) *Time of action of rainfall on the mosquito population.*

There are six occasions, scheduled in Table IV, when the effect of rainfall on the population is very clear. In each case the effect was not immediate, the population increase not commencing until 10 to 15 days after the causative rainfall. *The maximum population occurred between* 20 *and* 31 *days after the commencement of the rain*—(on the first four occasions the rain lasted only one or two days, and on the other two the heaviest rain fell at the beginning of the wet period, so the commencement is considered the best time from which to calculate its effects).

The correlation coefficient, which is based on the results for the whole period between 10th January and 27th October, confirms the deduction drawn from the six increases listed in Table IV, since Table III shows that *the maximum correlation* (the very high value of 0·793±0·064) *occurred when the mosquito population was compared with the rainfall* 24 *days previously.* The smaller but still high correlations obtained at the other periods are not necessarily significant, since the correlation between the rainfall at any period and the rainfall after 24 days was of the same order (0·5288± 0·125) and therefore these lesser correlations could be entirely a consequence of the greater correlation in the 24-day period—but in practice the correlations for the 16 and 32-day periods were probably partly determined by the direct effects of rainfall at this interval.

Inspection of Table III shows slight evidence of a negative correlation between rainfall and the average mosquito population eight days afterwards, since the correlation coefficient at this interval is lower (but not significantly so) than that between rainfall and the population in the same periods. Examination of fig. 8 shows that on each of the six occasions, scheduled in Table IV, where short periods of rainfall exerted a clear effect on the population there was a *decrease* in the eight-day average of the population for the period immediately following the eight-day period in which the rain occurred. These decreases were 44, 15, 8, 18, 22, 15, and 28 per cent. respectively. The size of the decrease is not correlated with the quantity of rain (many other factors also affect the population), and there are insufficient readings for statistical analysis, so that this decrease may have been fortuitous.

In the absence of larval data, the reason for the time-lag between cause and effect must be a matter of surmise. The direct effect of rain on the adults has been shown to be slight or absent. Probably the first consequence of heavy rainfall is the flooding of existing breeding places, thereby tending to wash away or expose to natural enemies some of the eggs, larvae, and pupae, and to disperse their normal food supply. Such results would explain a temporary decrease in the population, similar to that described above. Since the positive effects of tidal waters are visible after only eight days, at least some re-flooded areas must be immediately suitable for breeding, but whereas tidal flooding of gently sloping ground involves only a gentle submergence and emergence, heavy tropical rainfall produces rapid water movement in streams over the whole surface, followed for a variable interval by rapidly running seepages, and it is probably only when these have abated somewhat that optimum conditions

TABLE III.

Correlation Coefficients.

TIDE AND MOSQUITOS.		Daily tide height and 3-day average mosquito catch.				
		(*a*) Dry Season. 18th January to 5th June.				
Time-lag	5 days	6 days	7 days	8 days	9 days	10 days
Coefficient	0·112±0·088	0·169±0·086	*0·243±0·084*	*0·212±0·085*	*0·182±0·086*	0·055±0·089
		(*b*) Peak of dry season. 3rd March to 5th June.				
Time-lag	5 days	6 days	7 days	8 days	9 days	10 days
Coefficient	0·099±0·106	0·172±0·104	*0·380±0·092*	*0·446±0·086*	*0·462±0·084*	0·228±0·102
		(*c*) Wet season. 6th June to 5th October.				
Time-lag			7 days	8 days		
Coefficient			−0·125±0·091	−0·104±0·091		
RAIN AND MOSQUITOS.		8-day averages. 18th January to 20th October.				
Time-lag	Nil	8 days	16 days	24 days	32 days	
Coefficient	0·541±0·123	0·522±0·127	0·641±0·103	*0·793±0·064*	0·560±0·119	
RAIN AND RAIN.		8-day averages. 18th January to 20th October.				
Time-lag			16 days	24 days		
Coefficient			0·492±0·132	*0·529±0·125*		

occur, both for the larvae and their food supply. This difference is the most likely explanation of the long time-lag.

From the nature of the very varied breeding sites of *A. gambiae* and *A. melas*, it is obvious that although these conclusions may be widely applicable, they will not always be, and the extent of the time-lag will vary with local conditions. In areas where the production of *A. gambiae* is mainly from temporary puddles or rock pools it is probable that the time-lag is very short.

(c) *Quantitative relation between rainfall and the population.*

The correlation coefficient between mosquito population and rainfall showed the very high value of 0·793 ± 0·064 when the average population was compared with the average rainfall 24 days previously (Table III), so the size of the population bore a very close relation to the rainfall which preceded it. The regression equation obtained from the above 24-day correlation showed that for eight-day averages, where M = the average daily mosquito catch, and R = 1 inch rain per day, $M = 11{\cdot}9\,R + 5{\cdot}1$. Table V compares the observed population with the estimated population, calculated according to this equation, 24 days after the most pronounced periods of rainfall. Where the rainfall was preceded by rainfall of a similar order (14th February, 22nd June, 24th July), the observed values are less than the calculated values, but where the rainfall was much greater than that which had preceded it the observed population was as great or greater than the estimated population—a divergence explainable on the hypothesis that *increase in rainfall* exerted a greater effect than static rainfall on the level of the mosquito population.

Examination of the individual increases supports this hypothesis. The population level responded readily to the first four peaks of rainfall, which were also increases in rainfall, that of the previous weeks having been slight or non-existent. Then rainfall of 15·4 inches (0·96 inch per day) between 14th and 29th June had relatively little effect because the mosquito peaks were mixed with those due to the earlier rainfall of 4 inches (2 inches per day) of 4–5th June. A further 9½ inches of rain (1·9 inches per day) on 9–13th July, which in both daily rate of precipitation and eight-day average of rainfall was equal to, but not an increase upon, the maximum rainfall so far in that wet season, was unable to prevent a decline of 50 per cent. in the eight-day average of the mosquito population (see fig. 8). Thus an *increase* of rain of only 4 inches on 4–5th June produced 16 days later a population whose eight-day average level was 50 per cent. greater than that which was produced after the same interval by 9½ inches of rain, which was not an increase over previous levels, and which fell between 9–13th July. Later in the season two further periods of heavy rain, which were also marked increases over previous average levels, produced new peaks in the mosquito population (fig. 8).

Conversely, the effect of *decrease* in rainfall was shown at the end of the wet season, when the mosquito population decreased more rapidly than the rainfall, and from 20th October onwards the mosquito population dropped to about one per man per day, although the average rainfall was as great as during the one week in January when an *increase* of rainfall produced a large mosquito peak, rising to 13·8 per man per day: the population at this time was at a lower level than in March-April, when no appreciable rain had fallen for 2½ months.

The marked effect of variation in rainfall, as distinct from quantity of rain, on the size of the *A. melas* population can readily be appreciated by anyone with field experience of the collection of larvae of *A. gambiae* and *A. melas*. Maximum *A. gambiae* concentrations are usually found in rain-water puddles and similar localities, and frequently areas become suitable for breeding and then later become quite unsuitable—not merely is *A. gambiae* capable of breeding in temporary waters, but it seems to prefer them. For instance, Lamborn (1925) noted that in Nyasaland water collected in a newly-dug irrigation pit contained considerably more larvae than

TABLE IV.

Relation between rainfall and size of mosquito population.

Date of rain	Quantity of rain	Average initial room index	Average final room index	Increase	Date of increase	Date of peaks during increase (maximum peaks in heavy type)	Interval of peaks after commencement of heavy rain	Maximum peak-to-peak increase
17 Jan.	1·7″	4·9	13·8	180%	2–21/ii	4, **8**, 16/ii	18, **22**, and 30 days	130%
7 Apr.	0·1″	2·0	3·6	80%	19/iv–4/v	19/iv, **5/v**	12 and **28** days	110%
c. 5 May	1·6″	2·9	6·9	140%	21/v–6/vi	20/v, **4/vi**	15 and **30** days	10%
4–5 June	4″	6·0	23·2	285%	14–29/vi	20/vi, **28/vi**	15 and **23** days	270%
This increase fuses with that due to 15·4″ rain between 14-30 June, and the results are not separately identifiable, but they are visible until at least 15th July.								
21–30 July	13·7″	12·6	27·2	115%	9–17/viii	**10/viii**	**20** days	135%
18–23 Aug.	19″	15·0	34·6	130%	2–25/ix	12, 18/ix	25 and **31** days	295%
This increase is prolonged by heavy rain, 17·5″, between 27th Aug. and 3rd Sept.								

TABLE V.

Relation between observed and calculated size of population, for different levels of rainfall (Based on eight-day averages).

Dates of Rainfall	14 Feb. –26 Apr.	5–12 May	17–24 Jan.	29 May –5 June	22–29 June	24–31 July	17–24 Aug.
Quantity of rain, (R)	0″	1·1″	1·8″	4·1″	9·5″	13·3″	19·5″
Calculated population after 24 days ... (M=11·9 R+5·1)	5·1	6·8	7·8	11·2	19·2	24·8	34·0
Observed population	2·9	6·9	8·6	23·5	13·8	17·1	33·8

that in permanently filled pits, and I find that the same relation usually holds in similar pits in Sierra Leone. On one occasion, while surveying in the vicinity of Accra, Gold Coast, I found that *A. melas* was abundant in those brackish pools which had recently been dried, sun-baked, and re-flooded, and that other pools, otherwise identical, but not showing marks of drying, contained no larvae. (Both types of pools were without either fish or macroscopic vegetation.) Change of conditions probably liberates a very abundant temporary food supply, and natural enemies are much less likely to occur in temporary waters.

A relation between populations of *A. gambiae*, *sens. str.*, and rainfall has been established by workers in other localities, but their data have almost invariably been restricted to monthly averages, which produce much less informative indices, and they have not assessed the results in terms of correlation coefficients. Examples are provided by the work of Lamborn (1925) in Nyasaland, Garnham (1929) in Kenya, Barber and Olinger (1931) in Nigeria, Pomeroy (1931) in the Gold Coast, Gordon and others (1932) in Sierra Leone, and Wilson (1936) in Tanganyika, and early work is reviewed by Evans (1927). The work of Garnham and Wilson indicates that their *A. gambiae* were only affected by heavy rains. All these researches indicate that rainfall played an important part in determining the level of the *A. gambiae* population, but in some cases other climatic factors were also operative.

The work of Haddow (1942) introduced a new conception, for while he agreed with previous workers that the production of *A. gambiae* was dependent on local rainfall, he found that the correlation between the monthly catches of this mosquito and the monthly rainfall for the same month was low (0·4) and since his series of observations was small, the standard error was large (0·3) and the correlation coefficient was below the significant level. The reasons for the low correlation were probably mainly his use of very indelicate (monthly) indices, and the ignoring of the time-lag between cause and effect. Because the correlation was not significant, he concluded that the size of the population during an increase was not proportional to the amount of rain which had fallen, and that rainfall exerted only a qualitative effect.

The present work on *A. melas* leads to the contrary conclusion, and I consider that this conclusion normally applies also to *A. gambiae*, which is even more dependent on rainfall than *A. melas*, since it is not subject to tidal effects, but of course the degree of correlation between rainfall and population must vary widely in different localities, both with variations in the climate and in the type of breeding place, and in some exceptional areas the two factors may be uncorrelated, or, as in some cases of stream-breeding, negatively correlated.

(*d*) *Rate of change in the population size.*

The maximum eight-day average during the increase was compared with the average population in the 16 preceding days, and the average increases were 180, 80, 140, 285, 115, and 130 per cent., from 1·7, 0·1, 1·6, 4, 13·7 and 19 inches of rain respectively. If peak catches are compared instead of average catches, the increases were 130, 110, 10, 270 and 295 per cent. respectively but this result is more variable and I consider it a less reliable guide. An explanation of the method of assessing the fourth increase is required. This increase is due to 4 inches of rain which fell on 4–5th June. After an initial decline, the population rose to an eight-day average of 17·9 per man per day (= 200 per cent. increase) between 14th and 21st June, and to 23·2 (= 285 per cent. increase) between 22nd and 29th June. Heavy rain recommenced on 14th June, and 13·4 inches fell between 14th and 29th June. This rain could not have caused the increase recorded between 14th and 21st June, and in view of the time-lag previously mentioned as occurring in all the other cases, where the effects are not complicated, it is unlikely to have been even partly responsible for the increase recorded between 22nd and 29th June, but its effects have certainly merged with those of the storms of 4–5th June to produce the still further increase to 24·2 per man per day (= 305 per cent. increase) recorded between 30th June and 7th July.

Examination of the average increases shows that they are variable in quantity, and this is mainly due to variation in the quantity of the causative increase in rainfall: in the first four upswings, there is 80 per cent. increase after 0·1 inches, 140 per cent. increase after 1·6 inches, 180 per cent. increase after 1·7 inches, and 285 per cent. increase after 4 inches; but this relation is obscured in the last two increases by the very high initial rainfall and population.

Table IV shows that the rate of increase is variable as well as the quantity of increase: 180 per cent. increase with maximum peak 22 days after rain, 80 per cent. increase with maximum after 28 days, 140 per cent. and 30 days, 285 per cent. and 23 days, 115 per cent. and 20 days, and 130 per cent. increase with maximum peak after 31 days. Thus these figures do not support the principle enunciated by Haddow (1942), that the monthly rate of increase of *A. gambiae* is constant, the population during an increase being proportional, not to the amount of rain, but to the size of the initial population.

Haddow suggested that a definite threshold value (5 inches per month) was necessary at Kisumu before a definite increase occurred in the *A. gambiae* population, and that once this figure was passed, the population doubled in each succeeding month, irrespective of the quantity of rainfall. My results show no evidence of a threshold value for *A. melas*, and definite increases from small rainfall, varying in size with the quantity of rain. Examination of Haddow's own results show that they are incompatible with his conclusions, for analysis of the data given in his Table XXXVI, from which he drew these conclusions, shows great variation in monthly rate of increase, from 64 per cent. (March to April, 1940) to 340 per cent. (November to December 1940) while his Table XXXV shows that mean day catches in his control hut rose from 2·6 to 19·3, *i.e.* an increase of 640 per cent., from November to December 1940, a result quite incompatible with his hypothesis that the population size can only be doubled in a month.

Fig. 8 shows that the maximum average rate of increase in *A. melas* at Aberdeen occurred in mid-June. The 32-day average for the period ending 13th June was 4·9, while the 32-day average for the period commencing 14th June was 21·6, an increase of 340 per cent.—the greater part of this increase occurred between the eight days ending 13th June, population 5·2, and the following eight days, population 17·9, an increase of 240 per cent. between successive eight-day periods.

In the case of *A. melas*, tide enables substantial breeding to occur throughout the year, but this stabilising factor is absent for *A. gambiae*, whose population levels may be expected to alter more violently. Lamborn (1925) recorded greater monthly variation in *A. gambiae* in Nyasaland, where from November 1922 to January 1923 the monthly catch increased from 7 to 33 to 254, or 470 per cent. and 770 per cent. per month, and from December 1924 to February 1925 from 2 to 68 to 274, or 3,400 per cent. and 400 per cent. respectively.

The potential reproductive rate of Anophelines is so great that there is no reason to suppose that even in these increases the size of the initial population was an important limiting factor, a conclusion consistent with the even greater rate of population increase—1,000 per cent. and 1,060 per cent. in nine and eight days, respectively, in the temporary peaks of 5th and 20th May, which were due to tidal flooding.

PRACTICAL ANTI-MALARIAL IMPORTANCE OF THE RESULTS.

(i) *General considerations.*

The results show that in areas infested by *A. melas* malaria is an all-the-year-round problem. Normal dry season catches averaged about one-tenth of wet season catches, but a severe storm in the dry season temporarily caused the population to increase to at least one-half of its wet season level.

Although *A. melas* is influenced by tides, rainfall is the most important factor in determining its abundance. Mosquito peaks occurred 3–4 weeks after the causative rains, and malaria peaks will therefore occur about seven weeks after rainfall peaks.

Mosquito peaks are more dependent upon increase in rainfall than upon quantity of rainfall, and this relationship, which is attributed to their preference for temporary breeding places, will cause the distribution of the rainfall, as well as the quantity of rainfall, to play an important part in determining the malariousness of a season.

(ii) *Permanent anti-larval measures.*

In the absence of rain, spring tides are the main cause of the breeding of *A. melas.* In many areas such tidal effects could be eliminated by bunding, but in such cases extensive wet season breeding would still occur in the erstwhile tidal areas above the bund unless these were adequately drained.

(iii) *Temporary anti-larval measures.*

In the dry season, when there has been no appreciable rainfall for six weeks, temporary anti-larval measures against *A. melas* are only likely to be useful on the four days that follow maximum spring tides, but at other times either weekly oiling or dusting at four-day intervals with Paris green is necessary.

SUMMARY.

Daily catches of adult *A. melas* (= *A. gambiae* var. *melas*) were made in occupied huts at Aberdeen, Sierra Leone, from 10th January to 31st October, 1941. These catches are analysed with the following conclusions.

A. *Seasonal Variation.*

1. The average size of the adult population was closely determined by rainfall, but peak populations did not occur until 20–30 days after the causative rainfall, and there was an initial time-lag of about ten days before any response occurred. The correlation coefficient between rainfall and population size after 24 days (eight-day averages of both) was 0·793 ± 0·064, thus showing a very high degree of association.

2. Increase and decrease in rainfall exerted much greater effects on the size of the population than mere maintenance of the previous level of rainfall.

3. The rate of increase in the population after rainfall was very variable, and the maximum increase was 240 per cent. between the averages of successive eight-day

periods. There was no evidence that the size of the initial population ever controlled the limits of the increased population, and the maximum rate of increase after rain never approached that recorded after maximum tides in the dry season, when on two occasions the population increased tenfold in 8–9 days.

B. *Short-term Fluctuations.*

1. There were 29 marked peaks in the size of the *A. melas* population, which occurred at intervals of not more than 16 days. The amplitude of these fluctuations was greatest at the end of the dry season, when peak catches averaged eight times the minimum catches that had occurred only about eight days previously; during the wet season the amplitude was much smaller, and when the population remained fairly constant the average peak size was 45 per cent. above minimum.

2. In the dry season there were 10 periods of spring tides, and nine of these were followed by an Anopheline peak that occurred 7–9 days after the maximum tide. (On the tenth occasion a peak occurred on the twelfth day: compare this with the much longer time-lag after rainfall.) Apart from these nine mosquito peaks, there were only six other peaks during this season; two of these are attributed to a heavy storm and so correspond to wet season conditions. This association between maximum tides and *A. melas* peaks is mathematically significant ($P = \cdot 0015$).

3. For the whole dry season, the maximum correlation coefficient between tide and population was $0{\cdot}243 \pm 0{\cdot}084$, after seven days—a small but significant value. For the selected period in the complete absence of rain, the maximum value rose to $0{\cdot}462 \pm 0{\cdot}084$, after nine days. Hence, in the absence of rain, tide exerts a marked effect on the size of the population, but even small quantities of rain greatly reduce the importance of the tidal factor.

4. In the wet season there were nine periods of spring tides, but only three Anopheline peaks after 7–9 days. This relation was not significant, and the correlation coefficient was negative, but mathematically insignificant.

5. Combining the results from both seasons, and after elimination of the 12 peaks associated with tidal action, analysis showed that 13 out of the 17 remaining peaks occurred after an interval of either 4, 8, 12 or 16 days. (The tidal peaks bore no relation to these intervals.) There is less than 1 chance in 1,000 that this was a random distribution. Evidence is adduced that these were not due to the emergence of successive filial generations, but to overlapping generations, and the regularity of their occurrence is attributed to the effects of intra-specific competition.

6. Evidence of periodic fluctuations of wide amplitude in an *A. funestus* population is also provided.

ACKNOWLEDGMENTS.

This work would not have been possible without the facilities generously granted to me by my then Commanding Officer, Major G. Jameson Carr, M.B.E., and could not have been commenced but for the enthusiasm of Mr. P. Slater, Malaria Superintendent, Freetown, who obtained both the huts and the native personnel for the experiments. Various members of a Field Hygiene Section, R.A.M.C., and in particular my comrade, Pte. W. Wilkie, have helped very considerably. Several people have supplied valuable criticisms, and Dr. W. J. Martin has given me valuable help with statistical methods.

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CERATOPOGONIDAE COLLECTED IN TRINIDAD FROM CACAO FLOWERS.

By J. W. S. Macfie.

All the specimens referred to below were collected by Mr. A. F. Posnette in Trinidad, British West Indies, during December 1943 or in January 1944, and were sent by him to the Imperial Institute of Entomology, London, for identification, because some of them, he thought, were of importance in the pollination of cacao flowers. The majority (46) had been found actually in cacao flowers, and all but one of these were referable to the two species, *Forcipomyia quasi-ingrami*, Macfie (38) and *Lasiohelea nana*, Macfie (7). It was these two species which Mr. Posnette believed to be " of great economic importance in Trinidad as pollinators of cacao." The single exceptional specimen, which did not belong to either of these two species, was probably a small example of *Lasiohelea stylifer*, Lutz. With these insects were sent a few (8) other specimens from moss on the trunk of a cacao tree. They were, however, quite different species, namely, an *Atrichopogon*, a *Stilobezzia*, and a *Dasyhelea*. The following notes may facilitate the ready recognition and further study of these small insects.

Forcipomyia quasi-ingrami, Macfie.

Trinidad : xii.1943 to i.1944, 9♂, 29♀, " from cacao flowers " (*A. F. Posnette*).

These specimens vary considerably, *e.g.* length of wing in males 0·97–1·3 mm., in females 0·8–1·1 mm. ; last two segments of palp usually distinct and separate but in some almost or quite fused ; ratio of lengths of antennal segments 11 and 12 in males 10–13 : 33–43 units ; first tarsal segment of hind legs usually not swollen, in a few somewhat swollen ; T.R. in males 1·2–1·9, in females 1·4–2·1 ; and the two spermathecae varying in length from 56μ to 81μ, usually sub-equal, but in some unequal. They may represent more than a single species, but as I am unable to group them satisfactorily, I think they should all be regarded as forms of *F. quasi-ingrami*, a species which appears to be the Neotropical equivalent of *F. ingrami*, Carter. I found a number of both males and females very similar to these Trinidad specimens in a collection of Ceratopogonidae from Costa Rica sent to me for examination from the Deutsches Entomologisches Institut, Berlin, in 1939, and came to the same conclusion regarding them. My report should have been published in Berlin in the autumn of 1939, but I do not know what became of it. The females are similar to those from Brazil which I described in 1939 as possibly the females of this species.

Lasiohelea nana, Macfie.

Trinidad : xii.1943 to i.1944, 2♂, 5♀, " from cacao flowers " (*A. F. Posnette*).

The females agree well with the description of the type taken in Brazil, but are smaller, the length of the wing being only about 0·6 mm. and the dimensions of the other parts correspondingly less. The male, which had not previously been collected, is described below.

Male. Length of wing 0·7–0·8 mm., greatest breadth about 0·25 mm.

Head very dark brown. Eyes bare. Palpi brown, third segment only slightly inflated about middle, without pit : lengths of last three segments about 18, 8, and 8 units respectively. Antennae dark brown, with dark brown plume : segments 4–11 ranging from 8 by 7 to 8 by 5 units ; 12–14 elongate, narrow (2–3 units) distally, their lengths about 23, 13–14, and 9–10 units respectively ; 15 broader, about 15 (including stylet of about 2 units) by 6 units. *Thorax* and scutellum very dark brown the latter bearing 4–6 large bristles and several small hairs. *Wings* unadorned, well clothed with macrotrichia which, however, leave distinct bare areas along veins. No scales. Tip rounded; anal angle moderately well developed. Fringe as in female. Costa extending about half length of wing. First radial cell slit-like; second open, about same length as first. Fork of Cu at about same level as end of costa. Halteres with pale, brownish knobs. *Legs* almost uniformly brown, without scales. T.R. about 3. Form of segments, claws, and empodium normal. *Abdomen* dark brown but not so dark as thorax, without scales. Hypopygium complex, outline in ventral view appearing as shown in the figure (fig. 1 *a*). Aedeagus forming anteriorly a wide arch with well developed root-like processes, and extended posteriorly on each side as two well chitinised sclerites, the inner and larger one tapering, ending in a sharp point which in one specimen appears to be coiled; ventral wall difficult to distinguish but apparently membranous and terminating in two blunt processes. The hypopygium is unlike that of other species of *Lasiohelea* I have examined, but resembles somewhat that of *Thyridomyia palustris*, Saunders, although lacking the characteristic excavation of the ninth sternite " in the form of a Moorish arch."

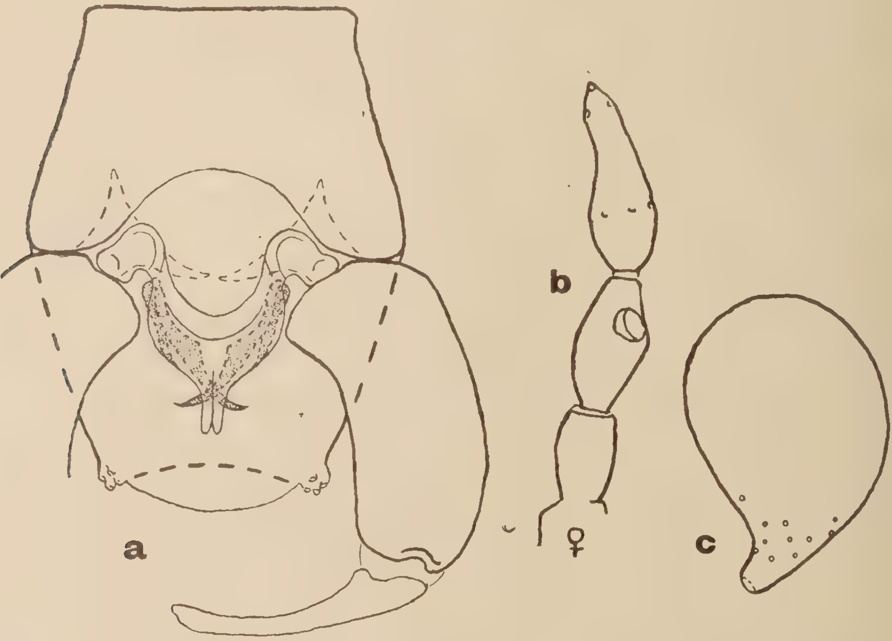

Fig. 1. *a, Lasiohelea nana,* Macfie, ventral view of hypopygium of male. *b, Atrichopogon brevipalpis,* sp.n., palp of female; *c,* spermatheca.

Lasiohelea stylifer, Lutz.

TRINIDAD: xii.1943 to i.1944, 1♀ (damaged), " from cacao flowers " (*A. F. Posnette*).

Atrichopogon brevipalpis, sp. n.

A brown or darkish brown species with the tip of the abdomen pale, yellowish, but tergites 2–6 conspicuously adorned with dark brown lateral patches, with segments

4 and 5 of the palps fused, with the T.R. about 3, and with a single retort-shaped spermatheca.

MALE and FEMALE. Length of wing about 1 mm., greatest breadth about 0·3 mm., slightly longer and narrower in male than in female.

Head dark brown. Eyes hairy in part at least. Palpi (fig. 1, *b*) pale brown, short segment 3 only slightly inflated but with a well-developed pit, segments 4 and 5 completely fused, tapering, together a little longer than 3 (in one female measuring 12 and 13 units respectively). Antennae brown, the terminal segments a little infuscated and bearing numerous small, leaf-like spines, and the 15th ending in a long (6-7 units) slender stylet. In male torus dark brown: segments 4–11 pale brown, ranging in one specimen from 10 by 8 to 10 by 6 units, and the plume pale, yellowish; 12–15 more elongate, their lengths in the same specimen 15, 27, 22, and 36 units respectively. In female segments 4–10 oval, armed with rather slender, curved, tapering spines about as long as the segments, and ranging in one specimen from 8 by 6 to 10 by 5 units; 11–15 elongate, their lengths in the same specimen 16, 18, 21, 21, and 34 units respectively. The combined lengths of segments 3–10, 4–10, and 11–15 about 72, 61, and 110 units respectively.

Thorax brown or darkish brown, with traces of usual adornment. Scutellum paler, yellowish, bearing in both sexes 4–5 centro-marginal bristles or hairs.

Wings unadorned. Macrotrichia lacking in male; in female scanty and confined to tip of wing, a fair number in cell R5, and a very few in cell M1 and at the ends of the enclosing veins, but with none elsewhere. Shape of wings and venation normal. Costa in both sexes extending not quite three-quarters length of wing. Radial veins almost without bristles. First radial cell very narrow and almost obliterated; second widely open, 3–4 times as long as first. Petiole of M in female about same length as cross-vein, rather shorter than cross-vein in male. Fork of Cu well distal to that of M, at about same level as distal part of first radial cell, and angle formed by branches of Cu less than right angle. Halteres with pale knobs.

Legs almost uniformly brown, only terminal segments of tarsi a little infuscated. Form of segments and bristles normal. Apical spine on tibia not exceptionally long, yellowish. T.R. about 3 in both sexes. Claws rather stout.

Abdomen with tip pale, yellowish, but tergites 2–6 conspicuously adorned with dark brown lateral patches. No ventral armature in female. Spermatheca (fig. 1, *c*) single, well chitinised, pitted at base, retort-shaped; the main portion oval, about 55μ by 48μ, the orifice opening into the duct narrow, diameter about 7μ. Hypopygium pale, yellowish-brown, without any very characteristic features. Ninth sternite bearing a transverse row of 4 bristles, feebly chitinised in middle, and apparently not excavated posteriorly. Arch of aedeagus wide, rounded, the anterior limbs well chitinised; the membranous distal portion voluminous. Claspers broadest at base, well clothed with small hairs and a few short bristles excepting at tip which is claw-like.

TRINIDAD: i.1944, 4♂, 2♀, "from moss on cacao trunk" (*A. F. Posnette*).

This species resembles in some respects *A. flavicaudae*, Macfie, an insect taken in Brazil of which only the female is known, but is much paler in colour and differs also in the form of the palps and the spermatheca.

Dasyhelea sp.

TRINIDAD: i.1944, 1♂ (damaged), "from moss on cacao trunk" (*A. F. Posnette*).

Stilobezzia sp.

A very dark brown species with the scutellum blackish and bearing four bristles, the first tarsal segment of the hind leg without a basal spine, the T.R. about 3, and the wings unadorned and without macrotrichia.

FEMALE. Length of wing about 1·2 mm., greatest breadth 0·4 mm.

Head very dark brown. Eyes bare. Palpi pale, brownish, third segment sub-cylindrical, without a definite pit; lengths of last three segments about 11, 7, and 12 units respectively. Antennae pale brown: segments 4–10 sub-cylindrical, ranging from about 13 by 5 to 17 by 4 units; 11–14 elongate, sub-equal, length 31–35 units; 15 longer, about 42 units. The combined lengths of segments 3–10, 4–10, and 11–15 about 113, 93, and 172 units, respectively.

Thorax very dark brown: bristles and hairs scanty, but a row of three bristles above root of each wing. No anterior tubercle. Scutellum very dark, blackish: bearing four rather small bristles.

Wings unadorned, the basal veins brownish. Tip rounded. Anal angle normal. No macrotrichia, and no bristles on radial veins. Microtrichia and fringe normal. Costa extending fully three-quarters length of wing. Two radial cells, both open: first small, rectangular, internal length and breadth about 10 and 3 units respectively; second much wider, about eight times as long as first. Cross-vein and distal portion of R5 almost in line. M with petiole much longer than cross-vein, its fork at about same level as middle of second radial cell. Fork of Cu a little proximal to level of fork of M. Halteres with pale knobs.

Legs brown, femora of four anterior legs with a broad median dark brown band, and tibiae of fore legs with a similar but less distinct band. Femora and tarsal segments 4 and 5 unarmed. First tarsal segment of hind legs without basal spine. T.R. about 3. Claws of four anterior legs about as long as 5th segment, with slender barb; those of hind legs about half this length, with short, stout, barb.

Abdomen with tergites very dark brown, but venter and tip paler, yellowish-brown. Spermatheca single, well chitinised, oval, about 75μ by 55μ; the duct portion narrow, about 10μ, and very short, about 4μ.

TRINIDAD: i.1944, 1♀, "from moss on cacao trunk" (*A. F. Posnette*).

This insect may belong to a new species but no name is suggested for it because only a single specimen is available for examination, and that is a female. In some respects it resembles *S. chaconi*, Macfie, a species also found in Trinidad, but of which only the male is known. In *S. chaconi*, however, the legs seem to be more conspicuously adorned, the femora of the four posterior legs being entirely very dark brown, and the T.R. is less, about two.

2

ON THE BIOLOGY OF *DYSDERCUS HOWARDI*, BALLOU.

III. THE EFFECT OF TEMPERATURE AND HUMIDITY ON THE LIFE-CYCLE.

By Elsie I. MacGill, M.Sc.

University of Manchester.

In his paper " Insects and Climate ", Uvarov stresses the need to determine the optimum conditions and the limits of temperature and humidity for the development of all stages of insects of economic importance. The present paper is an account of an attempt to define these conditions for one of the cotton stainers, *Dysdercus howardi,* Ballou. The experiments are not complete as, unfortunately, the stock of insects died out, and so far it has not been possible to obtain further supplies from Trinidad. Some conclusions have however been arrived at, and it seems worth while to put on record the results so far obtained.

Effect of Temperature and Humidity on Development of the Egg.

The first series of experiments was to find the optimum conditions of temperature and relative humidity for the development of the egg of *D. howardi.* Five relative humidities were chosen, 30 per cent., 66 per cent., 75 per cent., 82 per cent. and 100 per cent., and eggs in tubes maintained at these humidities by means of supersaturated salt solutions were kept at three different temperatures, 19, 21 and 24°C. All eggs at each temperature were from the same lots as the fertility of the egg-batches varied considerably.

The results of these experiments are given below:—

Relative Humidity	Temperature	No. eggs	Percentage hatched	Temperature	No. eggs	Percentage hatched	Temperature	No. eggs	Percentage hatched	Total eggs	Total percentage hatched
30 per cent. ...	19°C.	141	0	21°C.	115	0	24°C.	187	0	443	0
66 per cent. ...		136	5·1		116	29·0		162	12·9	414	15·0
75 per cent. ...		137	15·4		116	42·8		156	54·4	409	39·0
82 per cent. ...		165	5·4		146	53·4		137	46·0	448	33·0
100 per cent.		177	10·7		126	49·2		254	28·0	557	27·5

No nymphs were hatched at 30 per cent. relative humidity at any of the temperatures used, and it seemed that this was definitely too dry for the development of the eggs of *D. howardi*; 66 per cent. relative humidity, although some eggs hatched at each degree of temperature, appeared less favourable than the three higher relative humidities. With regard to temperature, 19°C. seemed less suitable than the higher temperatures for the development of the eggs.

While the above experiments had been going on, it had been found that the nymphs and adult insects appeared to thrive better in a higher temperature than had been used in the egg experiments. Eggs, therefore, were kept at 20 and 27°C. at the three higher relative humidities with the following results:—

Temperature	Relative Humidity	No. eggs	Percentage hatched	Relative Humidity	No. eggs	Percentage hatched	Relative Humidity	No. eggs	Percentage hatched	Total eggs	Percentage hatched
20°C. ...	75%	797	12·1	82%	687	22·1	100%	857	23·2	2,334	19·1
27°C.		799	34·7		677	41·3		856	46·0	2,332	40·8

The optimum temperature for the survival of the eggs of *D. howardi* is nearer 27 than 20°C. at all three of the relative humidities; approximately twice as many eggs hatched at the higher temperature at 100 per cent. and 82 per cent., and nearly three times as many at 75 per cent. relative humidity.

The optimum humidity could not be deduced from the above experiment as only the eggs in the same humidity came from the same batches, so a further test was made in the optimum temperature.

Temperature	Relative Humidity	No. eggs	No. hatched	Percentage hatched
27°C.	75%	8,534	3,197	37·4
	82%	9,150	3,992	43·6
	100%	9,449	3,762	39·8

From these two experiments it appeared that 27°C. and 82 per cent. relative humidity gave optimum conditions for the survival of the egg of *D. howardi*, though conditions at 75 per cent. and 100 per cent. were nearly as good.

The effect of temperature on the mortality of the egg was next considered, with special reference to the temperature limits of the species. Shelford considers that an ideal series of experiments should include "(*a*) constant temperature experiments at 2-5°C. intervals from 5-39°C. with humidities 45-100 per cent. at 10 per cent. intervals; (*b*) variable temperature experiments within the limits of possible weather conditions; (*c*) out-door observations." Experiments in the first section were begun but there was only time to finish a fairly complete series at 100 per cent. relative humidity and different degrees of temperature and a smaller number at 75 and 82 per cent. relative humidity before the stock of insects showed signs of deterioration.

As has already been stated, the number of fertile eggs in each batch of eggs laid by a female stainer varies considerably; in every case the batch of eggs used was therefore divided, and half the eggs were kept at 27°C., provisionally regarded as the optimum temperature, as a control. The number of eggs hatched at 27°C. was considered to be the maximum possible, and the results at other temperatures are given as percentages of the number hatched at 27°C.

The following table gives the results:—

TABLE I.

No. eggs	Temperature	No. hatched	Percentage hatched	Temperature	No. hatched	Percentage of eggs hatched at 27°C.
100% Relative Humidity						
2,910	27°C.	265	17·1	18–19°C.	0	0
2,546	27°C.	371	29·2	20–21°C.	23	6·2
2,880	27°C.	381	26·4	22–23°C.	145	38·0
3,320	27°C.	578	34·8	24–25°C.	500	86·5
462	27°C.	38	16·8	26°C.	36	96·4
3,020	27°C.	535	35·4	29–30°C.	345	64·6
2,876	27°C.	398	27·6	31–32°C.	150	37·7
2,750	27°C.	361	26·2	33–34°C.	0	0
82% Relative Humidity						
834	27°C.	144	35·0	18–19°C.	4	2·7
1,862	27°C.	430	46·2	20–21°C.	153	35·5
358	27°C.	75	41·1	22–23°C.	51	67·1
756	27°C.	86	20·6	24–25°C.	79	91·8
386	27°C.	21	10·8	29–30°C.	33	157·1
206	27°C.	50	48·5	31–32°C.	16	32·0
180	27°C.	25	27·7	36°C.	0	0
75% Relative Humidity						
1,856	27°C.	304	32·7	20–21°C.	112	36·1
142	27°C.	23	22·3	24–25°C.	25	108·6
170	27°C.	31	36·4	31–32°C.	31	100
86	27°C.	11	25·6	40°C.	0	0

In every case the percentage of nymphs hatched from the eggs is low, as many of the eggs are infertile, even where copulation has occurred. In the present experiments the percentage of hatching at 27°C. varied between 10·8 and 48·5 per cent. with an average of 29·5 per cent.

The results of the experiments confirmed the view that 27°C. is approximately the optimum temperature for the survival of the eggs of *D. howardi* in a saturated atmosphere though over 60 per cent. of the possible nymphs were hatched at temperatures ranging from 24-30°C. The stainer proved to have a comparatively limited range of temperature for the development of the egg; temperatures of 33°C. and over were lethal before incubation was completed though development continued for some time at 33 and 34°C. No nymphs were obtained at temperatures below 20°C. in this series, although in earlier experiments a few eggs had hatched at 19°C. and 100 per cent. relative humidity, but again development could be seen in eggs kept at 17-18°C. though none survived to complete their incubation. Experiments at 82 per cent. relative humidity suggested that the eggs had a slightly wider range of temperature for survival than at 100 per cent. A few eggs hatched at 19°C., and the percentage that hatched at 20-21°C. was higher than in the previous series. The optimum temperature may also be a little higher at this humidity as more eggs hatched at 29-30°C. than at 27°C., but as the number of eggs kept at this temperature was small and included an unusually large number of infertile eggs (only 10·8 per cent. hatched at 27°C.), further experiment at 29-30°C. would have been useful to test this result more fully. The number of experiments at 75 per cent. relative humidity was too few to give more than a very general indication of the effect of temperature on the mortality of the egg. Temperatures of 24-32°C. appeared to be suitable for the incubation of the eggs of *D. howardi,* and a larger percentage hatched at 20-21°C. than at 82 per cent. or 100 per cent. relative humidity. No eggs were kept at temperatures below 20°C. in this series but the larger number of nymphs obtained at 20-21°C. suggests that the lower limit of temperature may be slightly below that at 100 per cent. relative humidity. No eggs were tested between 32 and 40°C., but as many eggs hatched at 31-32°C. as at 27°C., and it is possible that, as at 82 per cent. relative humidity, the optimum temperature may be a little higher than at 100 per cent. relative humidity.

The optimum temperature for any stage of an insect's life cycle has been defined as a temperature range at which the relatively greatest percentage of individuals complete their development within the relatively shortest period. The optimum temperature for the survival of the eggs of *D. howardi* has been found to be 27-29°, and the following table gives the length (in days) of the incubation period at various temperatures.

TABLE II.

Temperature	Length of incubation period in days		
	100% Relative Humidity	82% Relative Humidity	75% Relative Humidity
31°–32°C.	5·7	6·3	5·6
29°–30°C.	5·9	5·3	—
27°C.	5·9	5·9	5·9
26°C.	6·8	6·2	6·6
24°–25°C.	8·1	8·0	10·0
22°–23°C.	10·3	10·0	—
20°–21°C.	11·0	11·7	10·9
18°–19°C.	—	14·0	—

At 100% relative humidity the incubation period varied from 5·7 days at 32°C. to 11 days at 20°C. At 27°C. the egg took 5·9 days to hatch, a little longer than the minimum time but near enough, taking into account the much larger number of eggs to survive, for 27°C. to fulfil the conditions for the optimum temperature in a saturated atmosphere. Below 27°C. the time of incubation lengthened rapidly and at 20-21°C. was almost twice as long as the optimum temperature. At 82% relative humidity the time of development varied from 5·3 days at 29-30°C., approximately the optimum temperature, to 14 days at 18-19°C. the latter being the lowest temperature at which eggs hatched at any relative humidity. The variation in the time of incubation at 75% relative humidity was from 5·6-10·9 days.

In the following graph (fig. 1) the velocity lines for the development of the egg of *D. howardi* have been calculated from the reciprocals of the time of development. The reciprocals and the velocity lines are plotted against temperature. The theoretical " threshold of development ", that is the point at which the velocity line cuts the temperature axis, is between 11 and 12°C. for each of the three degrees of relative humidity. This is considerably below the lowest temperature at which eggs hatched, but, as has already been stated, some development did occur at temperatures below 18-19°C. though none of the eggs survived long enough to hatch. The " threshold of development " varied slightly at each of the three degrees of relative humidity used in the experiments. The three points are 11·7°C. for 100%, 11·5°C. for 82% and 11·6°C. for 75% relative humidity; this lends support to the conclusion reached earlier that the lower temperature limit for the hatching of the eggs falls at lower relative humidities.

The degree of relative humidity did not appear to have a marked effect on the length of the egg stage in *D. howardi*, eggs at the different relative humidities took approximately the same time to hatch in the same temperature. The greatest variation at any temperature was 24-25°C. where the time varied from 8 days at 100% and 82% relative humidity to 10 days at 75%, but at 75% all the eggs that hatched belonged to the same batch and as there was at all temperatures a

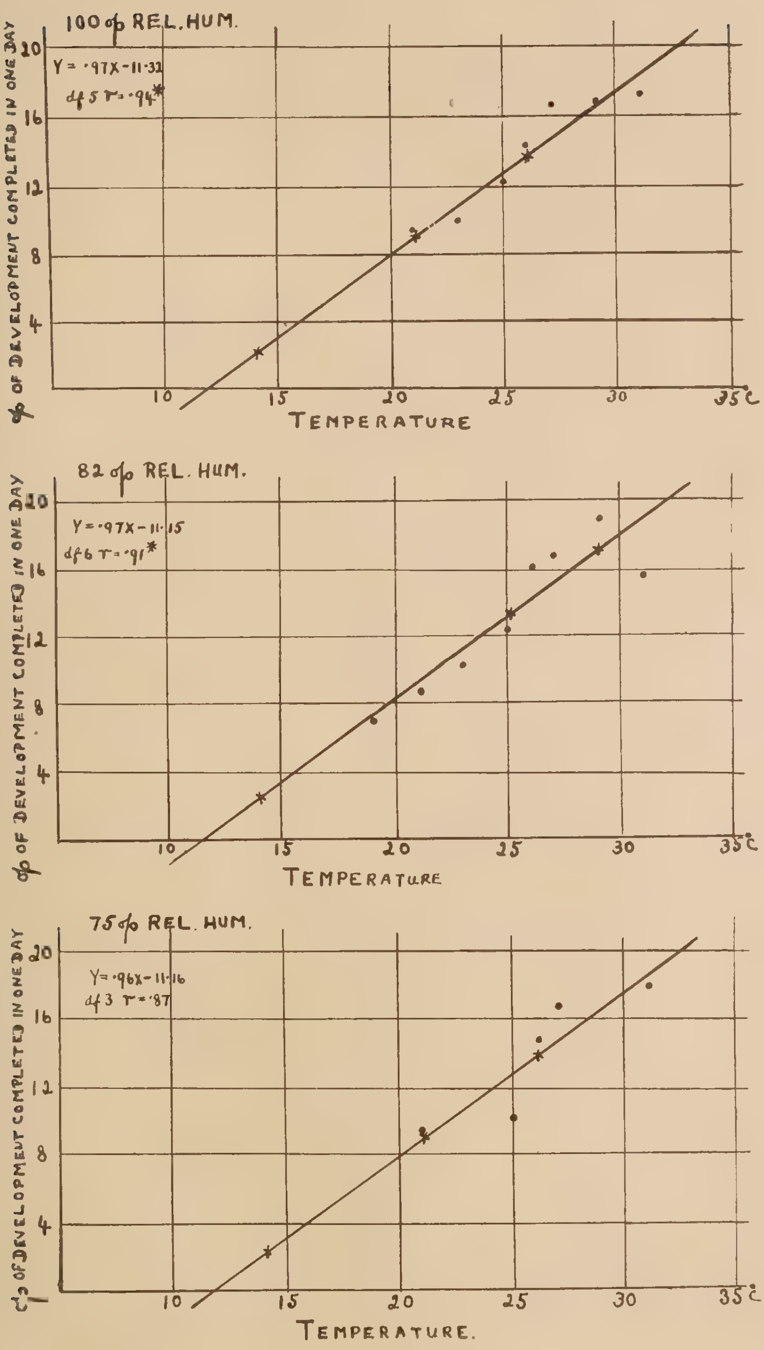

FIG. 1.—Velocity lines for the development of the egg of *D. howardi* at the different temperatures and three degrees of relative humidity. * = Highly significant.

certain amount of variation between different batches of eggs, 10 days at 24-25°C. and 75% relative humidity may represent the maximum time and not the average time of incubation.

It has been found that in some species of insects the time of development of the different stages varies not with the relative humidity but with the absolute humidity of the atmosphere; the velocity line for the development of the egg of *D. howardi* at different vapour pressures has therefore been calculated from the following table and shows significant correlation between the absolute humidity of the atmosphere and the length of the egg stages.

TABLE III.

V.P. (mms.)	Incubation (days)	Reciprocal observed	Values (x 100) calculated	Difference
13·12	14	7·1	9·14	— 2·04
13·7	10·9	9·2	9·34	— ·14
14·75	11·7	8·5	9·99	— 1·49
16·7	10·0	10·0	11·0	— 1·00
17·25	10·9	10·0	11·29	— 1·29
18·00	11·0	9·1	11·68	— 2·58
18·85	8·0	12·5	12·12	+ ·38
19·00	6·6	15·1	12·2	+ 2·9
20·00	5·9	16·9	12·72	+ 4·18
20·4	10·3	9·7	12·92	— 3·22
20·5	6·2	16·1	12·98	+ 3·12
22·00	5·9	16·9	13·76	+ 3·14
23·00	8·1	12·3	14·28	— 1·98
25·21	6·8	14·7	15·42	— ·72
25·25	5·3	18·8	15·45	+ 3·35
26·00	5·6	17·8	15·84	+ 1·96
26·7	5·9	16·9	16·2	+ ·7
28·25	6·3	15·8	17·01	— 1·21
30·7	5·9	16·9	18·28	— 1·38
34·5	5·7	17·5	20·26	— 2·76

In fig. 2 the velocity line for development is plotted against vapour pressure.

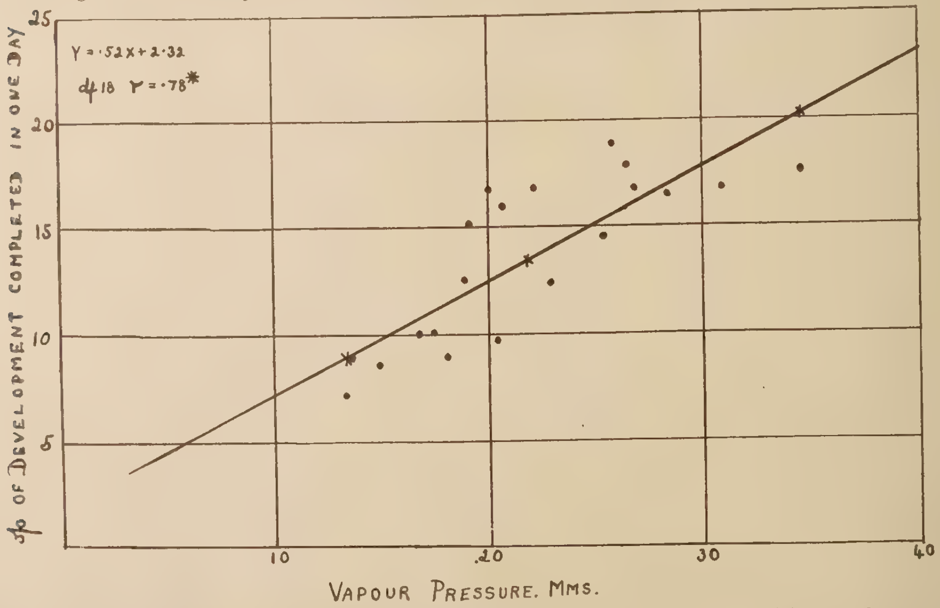

FIG. 2.—Velocity line for the development of the egg of *D. howardi* at different degrees of absolute humidity. * = Highly significant.

Effect of Temperature on Oviposition.

Two temperatures, 20 and 27°C., were used to find the effect of temperature on copulation and oviposition in a saturated atmosphere with the following results:—

Temperature	Average time between last moult and copulation	Average time between last moult and first batch of eggs	Average no. of eggs per female	Average no. of batches of eggs per female
27°C.	2·8 days	8 days	141·9	2
20°C.	5·5 days	15·8 days	164·4	2·2

Temperature	Eggs		Maximum eggs per female	Maximum batches per female
	Largest batch	Smallest batch		
27°C.	164	5	486	5
20°C.	103	19	494	5

Although 20°C. was definitely below the optimum temperature for the development of the egg of *D. howardi,* the lower temperature had little effect on the number of eggs laid. The average number of eggs and the maximum eggs per female were both slightly higher at 20°C. than at 27°C., though the largest single batch of eggs was laid at 27°C. The lower temperature slowed up the life-cycle very considerably; the average time between the last moult of the female and copulation was about twice as long at 20°C. as at 27°C., the time between the last moult of the female and the first batch of eggs laid was 8 days at 27°C. and 15.8 days at 20°C. and, as has already been shown, the egg took approximately twice as long to hatch at 20°C. as at 27°C. The average length of life of the female *D. howardi* was 25 days at 20°C. and 11 days at 27°C., while the maximum age reached by a female was 75 days at 20°C. and 37 days at 27°C., again the time at 20°C. was double that at 27°C.

Effect of Temperature on Mortality of the Nymph.

The numbers of nymphs surviving in each instar at two temperatures are given in the following table:—

TABLE IV.

Temperature	No. 1st instar	No. reaching 2nd instar	Percentage 1st reaching 2nd instar	No. reaching 3rd instar	Percentage 1st reaching 3rd instar
27°C.	1,000	823	82·3	595	59·5
20°C.	386	322	83·4	238	61·6

No. reaching 4th instar	Percentage 1st reaching 4th instar	No. reaching 5th instar	Percentage 1st reaching 5th instar	No. becoming adult	Percentage 1st becoming adult
507	50·7	426	42·6	269	26·9
207	51·0	131	33·9	65	16·8

A slightly higher percentage of nymphs survived the first three moults at 20°C. than at 27°C., but the percentage of first-instar nymphs reaching the fifth and adult stages was considerably higher at 27°C. than at 20°C.; thus the optimum temperature for the survival of the nymphs, as for the eggs, is nearer 27°C. than 20°C.

Summary.

1. Experiments were made to find the effect of temperature and relative humidity on the biology of *Dysdercus howardi*.

2. The optimum temperature for the survival and incubation of the eggs in a saturated atmosphere was approximately 27°C. The temperature range for the development of the eggs was 19-32°C.

3. Relative humidities of 75% and higher gave suitable conditions for the development of the eggs; 30% relative humidity was lethal to the eggs.

4. The " threshold of development " for the egg is considerably lower than the lowest temperature at which eggs will hatch.

5. The range of temperature appears to be wider and the " threshold of development " lower at 82% and 75% than at 100% relative humidity.

6. There is a correlation between the degree of absolute humidity and the incubation period.

7. The length of the life-cycle is approximately twice as long at 20°C. as at 27°C.

8. The optimum temperature for the survival of nymphs to reach the adult stage is nearer 27°C. than 20°C.

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THE HISTERIDAE ASSOCIATED WITH STORED PRODUCTS.(*)

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Introduction.

Fourteen species of the family Histeridae have been found in various parts of the world in stored food or in warehouses and other building structures used to store dry animal or vegetable products. Of these, the four that have not yet been found in the British Isles are: *Teretriosoma americanum* (Lec.), *Hypocacculus metallescens* (Er.), *Saprinus semipunctatus* (F.), and *Carcinops mayeti*, Mars. Keys and full descriptions are given for ten species, but four others, which appear to be more or less accidentally associated with stored products, are only included in the keys. Under the headings of the ten more important species will be found summaries of their distribution and habits. The synonymy given for the various species has been in the main restricted to names current in the economic and biological literature. An attempt has been made to define the family both as regards adults and larvae and to give a summary of the biology and ecology of the whole family.

The three drawings of the whole insects were done by Mr. A. Smith. All other figures were drawn by me with the aid of a *camera lucida*, and lines next to figures refer to a length of 0·20 mm. unless otherwise indicated. The adults were described under a magnification of × 75.

Characters of the Family.

Adults.

About 3,200 species of Histerids have been described, and these are now placed in 10 subfamilies and about 200 genera. Most of the species are 1-10 mm. long, but a few are considerably larger, and one, *Oxysternus maximus* (L.), attains a length of 30 mm. The body is always compact and usually oval and strongly convex but is sometimes cylindrical and sometimes strongly flattened. The cuticle is hard and heavily sclerotised and is usually strongly shining and black or reddish brown, but in a number of the Saprininae the cuticle may have a strong metallic brassy, blue, or blue-green lustre and a few have conspicuous red or yellow markings on the elytra.

The head can be almost entirely retracted into the prothorax and is usually hypognathous, but in the Hololeptinae and Trypanaeinae it is prognathous. A

(*) The two previous papers in this series are :—" The Ptinidae of economic Importance."—Bull. ent. Res., **31**, 1941, pp. 331–381, 59 figs., and " The Lathridiidae of economic Importance."—*Ibid*, **32**, 1941, pp. 191–247, 67 figs.

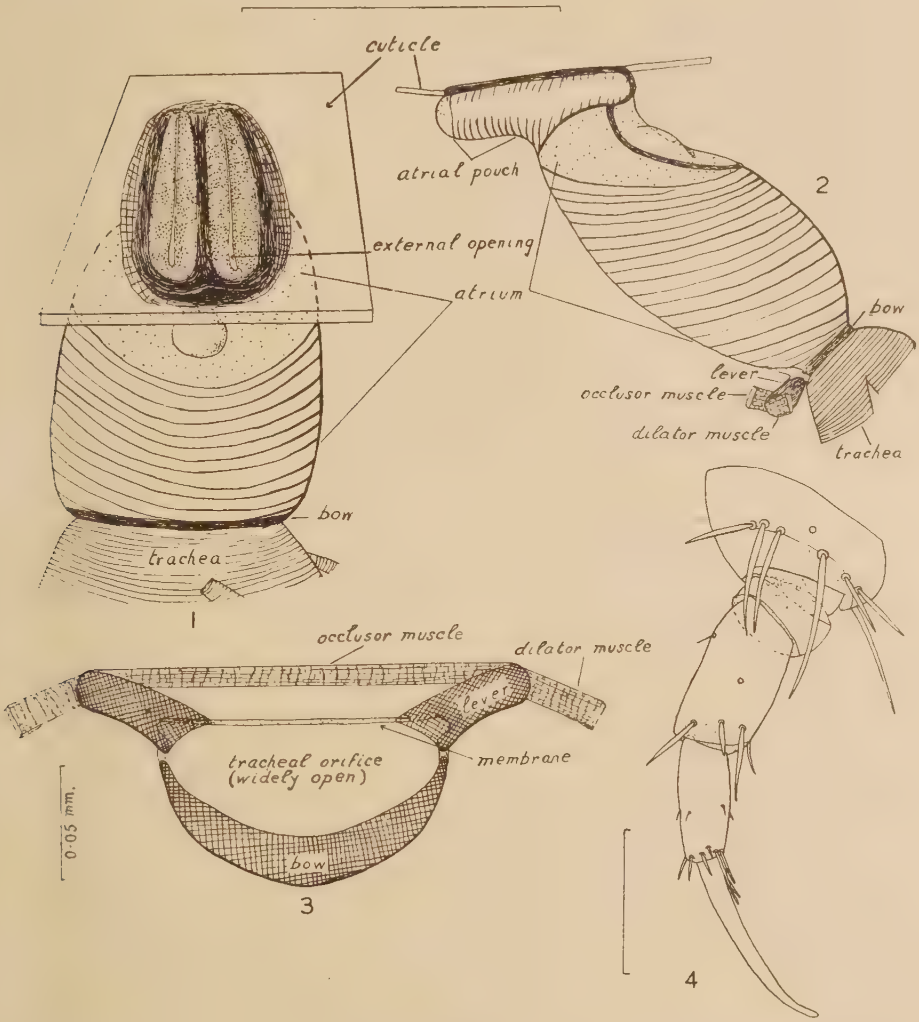
groove which receives the antennal scape is present on the ventral sides in front of the eye. The antennae have a long and often very thickened and dilated basal segment or scape, a 6- or 7-segmented funicle which forms a distinct angle with the scape so that the antennae are elbowed (geniculate), and a large solid club which sometimes has transverse sutures distinctly marking the boundaries of the three segments of which it is formed. The mandibles are large, stout, and often strongly projecting. The maxilla has a densely setose galea and lacinia and a 4-segmented palp. The labial palpi are 3-segmented. The prothorax always fits very closely on the base of the elytra, and on its ventral surface antennal cavities are present on the sternum or hypomeron. The elytra are truncate behind and do not cover the propygidium or pygidium except in some ABRAEINAE. The hind wings are usually well developed, and the venation is of the Staphylinid type, *i.e.*, the median and cubitus do not form a loop in the distal part of the wing. The mesosternum is short and broad and there is frequently no dividing suture between it and the large metasternum. The mesosternal episternum is very large and frequently extends between the bases of the prothorax and elytra so that it is visible from above. The abdomen has five free and externally visible sternites, and the first of these appears to consist of the sternal elements of the second and third segments. There are seven external abdominal tergites of which the sixth (propygidium) and seventh (pygidium) are very rarely covered by the elytra, and the seventh is nearly always very large and more or less vertically inclined. The legs are more or less flattened and can be closely retracted against the body. The coxae are all widely separated, the hind pair being particularly widely separated. The anterior coxae are strongly transverse, and their cavities are open behind. The tarsal formula is 5-5-5 except in the genera *Aeletes* and *Acritus* where it is 5-5-4.

The Histerids associated with stored products may be distinguished from all other beetles found in similar situations by possessing the following combination of characters: Antennae elbowed and with a large and solid club; prothorax with ventral or antero-ventral antennal cavities; elytra shortened so that two apical abdominal tergites are exposed; and abdomen with a large and more or less vertically inclined pygidium and five externally visible sternites. The hard, compact, and convex body with a strongly shining black or reddish brown cuticle adds greatly to the distinctive appearance of the members of this family.

Larvae.

The larvae are usually narrow and subparallel and elliptical in cross section. The cuticle is whitish but the head and thoracic tergites are generally brownish and well sclerotised. The thoracic sternites are also often sclerotised.

The head is prognathous with exserted mouth-parts. It may be broader than long as in *Hister* or distinctly longer than broad as in *Carcinops*. The labral, clypeal, and frontal sclerites are always fused together, and in second and third instar larvae the coronal and frontal sutures are usually altogether absent. The middle anterior margin of the head is always distinctly toothed, and on antero-lateral side there is usually a fringe of long setae which often arise from a feebly sclerotised area. The 3-segmented antennae are inserted above the basis of the mandibles and are always shorter than the head. There are two or three sensory cones on or near the apex of the second segment. Ocelli are often absent but some (*Hister, Dendrophilus, Epierus*) have a single ocellus on each side of the head. The mandibles are large, sickle-shaped, and usually have one or two prominent teeth on the middle of the cutting edge though teeth are absent in the TERETRIINAE. Near the base of each mandible there is apparently always a thick brush of long setae which are often secondarily spinose apically. The maxilla has the cardo and stipes fused together to form a subcylindrical segment. The cylindrical galea is inserted on the palpiger (usually counted as the first segment of the palp) and has a long apical seta. All trace of the lacinia appears to be lost. The palp—including the palpiger—is usually 4-segmented but may be 5-segmented (TERETRIINAE). The labium is without a ligula and the palpi are 2- or (TERETRIINAE) 3-segmented.


cuticle
atrial pouch
2
external opening
atrium
bow
lever
occlusor muscle
dilator muscle
trachea
bow
trachea
1
occlusor muscle
dilator muscle
lever
membrane
tracheal orifice (widely open)
0·05 mm.
bow
3
4

FIGS. 1–4.—*Hister cadaverinus*, Hoffm., third-instar larva. (1) Eighth abdominal spiracle. (2) Lateral view of same. (3) Closing mechanism of eighth abdominal spiracle. (4) Anterior face of right front leg.

The abdomen is 10-segmented. The tenth segment is short, tubular, and serves as a proleg. The ninth bears a pair of 2-segmented, rarely 1-segmented, urogomphi which may be heavily sclerotised (*Hister*) or nearly membranous (*Dendrophilus*). Urogomphi are known to be absent in some termitophilous forms. The first eight tergites and sternites sometimes, *e.g. Hister*, have transverse series of small, acute, well-sclerotised tubercles. In some termitophilous forms there are fleshy, conical protuberances on the first eight pleurites and sternites. The spiracles are biforous.(*) The legs are short and 5-segmented with short and widely separated coxae. The single claw is sometimes longer than the tibio-tarsal segment.

The whitish and parallel-sided body and prognathous head with protruding mouthparts and prominent, curved mandibles together with the 10-segmented abdomen and 2-segmented urogomphi make for the very distinctive appearance of Histerid larvae. Superficially, they resemble the CARABIDAE, but may at once be distinguished by their 5- instead of 6-segmented legs. They also resemble the HYDROPHILIDAE to which they are closely related and like them have the galea inserted on the palpiger. However, Histerid larvae differ in having a brush of long setae near the base of the cutting edge of the mandible, the cardo and stipes of the maxilla fused together, and no or only one ocellus on each side of the head. Most of the HYDROPHILIDAE that have been found with stored products have an 8-segmented abdomen, the eighth segment forming a breathing chamber which contains the caudal pair of spiracles.

Biology.

Most of the species lay in the spring or early summer, and the eggs are deposited singly or in small groups. The eggs are usually oblong-oval, slightly curved, and rounded at both ends. The surface is smooth and whitish. The eggs of some are unusually large. In *Platysoma punctigerum*, Lec., they are nearly a third, and in *Hister cadaverinus*, Hoffm., they are more than a third as long as the female. In *Plegaderus nitidus*, Horn, however, they are less than one-twentieth as long as the female and are acorn-shaped with a cap-like structure at the broad end.

There are always three larval instars, the third larval moult releasing the pupa. When ready to pupate, the larvae may fashion a pupal " cocoon " which consists of fragments of the substratum glued together and lined on the inside with a smooth layer. According to Reichardt (1941), a pupal cocoon of this kind is made by the larva of *Hister unicolor*, L., in dung, and *Saprinus tenuistrius*, Mars., in sand. Other species, *e.g. Abraeus globosus* (Hoffm.), pupate in a round cell in rotten wood but do not make a cocoon.

In temperate climates there is, as a rule, one generation a year, and the winter is passed only in the adult stage. Eggs laid in the spring hatch into larvae which do not pupate until late summer or autumn, and the adults, which emerge after a few weeks, hibernate without laying. Occasionally there are two generations a year. In California *Platysoma punctigerum*, Lec., lays about the end of May, and larvae hatching from these eggs become adults by August and produce a second brood in September and October; and it is the adults of this second generation that overwinter (Struble, 1930). The life-cycle of this species requires seven to nine weeks, whereas that of *Plaesius javanus*, Er., normally takes eight months.

The majority of the species appear to be diurnal although *Exaesiopus torrus*, Rchdt., flies before and after sunset and *Teretrius acaciae*, Reitt., is known to come to light at night (Reichardt, 1941). A characteristic peculiarity of nearly all HISTERIDAE is their instinct to feign death by withdrawing the head into the

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(*) The prothoracic and abdominal spiracles are similar in structure. The primary atrial aperture is completely closed, at any rate between moults. Each spiracle (fig. 1) has two functional external openings each of which consists of a narrow, dorsal, median slit along the long axis of the atrial chamber or pouch. These openings are clearly visible in well stained specimens of *Hister cadaverinus*, Hoffm., but their use has also been verified experimentally by submerging living larvae in water. If the atrial chamber of these larvae is gently squeezed, a bubble of air will be given off from the slit. The spiracles have no external openings in the position described by Steinke (1919) and Böving & Craighead (1931). It is worth noting that in his description of biforous spiracles (HYDROPHILIDAE, DRYOPIDAE, LAMPYRIDAE, etc.) Steinke (*op. cit.*) has consistently failed to note the true functional openings, and he has described the outer scar of the preceding spiracle as the external opening. The spiracles of the LAMPYRIDAE, DRYOPIDAE, etc., are similar in origin to the dorsal spiracles of Dipterous larvae.

prothorax and closely retracting the legs beneath the body when touched or alarmed in any way. Most adult Histeridae run rather slowly, but some of the long-legged myrmecophilous Haeteriinae are said to be able to run very quickly. None is known to produce sound, and stridulatory organs are unknown in the family.

The habits and life-histories of only a few Histerids are known in detail. However, something is known of the food of a considerable number, and it is probably safe to say that both as larvae and adults they are an exclusively carnivorous group. Their food consists of small Arthropods, chiefly mites and larvae of insects. Species of *Dendrophilus* and *Saprinus* kept in the laboratory would feed on raw and cooked meat, and it therefore seems likely that many of the species found in carrion may occasionally feed on the carrion itself though their normal food in carrion is fly and beetle larvae.

While most Histerids will probably prey on many kinds of mites and insects, a considerable number are restricted to one or only a few hosts either through the nature of their habitat or because they exercise a certain amount of selection. This host specificity is particularly evident amongst a large number of myrmecophilous species. Many of these ant-loving forms are restricted to the nests of one genus or even one species of ant. The Indo-Malayan *Plaesius javanus*, Er., preys on the larvae of weevils of the genera *Sphenophorus* and *Cosmopolites* and has been found useful in controlling the depredations of these weevils. *P. javanus* has been introduced into Queensland, Jamaica, and Trinidad to help to control the banana weevil borer, *Cosmopolites sordidus*, Chevr. *Pachylister chinensis* (Quens.) has been introduced into Fiji from Java to help to control the common housefly. Another species, *Oxysternus maximus* (L.) has been found useful in the control of the palm weevil, *Rhynchophorus palmarum* (L.). Two species prey on Chrysomelid larvae, *Saprinus virescens* (Payk.) on *Phaedon armoraciae* (L.) on watercress, and *Hister helluo*, Truqui, on *Agelastica alni* (L.) on alder. Both of these species hunt the Chrysomelid larvae on the leaves of the plants mentioned, a very unusual habit in the family. Other species which apparently have a preference for particular larvae are; *Hister holubi*, Schm., on *Tinaea vastella*, Zell., in horns and hoofs, and *Platysoma punctigerum*, Lec., on *Dendroctonus brevicomis*, Lec., in the bark of yellow pine.

From the point of view of the type of habitat occupied, the Histeridae may be placed in five main groups: (1) saprophiles, (2) inhabitants of bird and animal nests, (3) troglobionts, (4) inhabitants of the burrows of wood-boring beetles, and (5) myrmecophiles and termitophiles. This ecological grouping has been discussed in some detail by Reichardt (1941). The saprophiles or inhabitants of dung, carrion, and decaying vegetable matter are the most numerous group in the family. They are nearly all broadly oval, strongly convex, short-legged species, and the most obvious adaptation to their mode of life is the hard, polished, and hairless cuticle to which liquid or semi-liquid decaying matter does not easily adhere. Those that are found in carrion are usually attracted to it in the fifth or ammoniacal stage of decomposition, that is, in a stage when there is usually no lack of fly or beetle larvae.

The inhabitants of bird and animal nests are a small group which do not show any obvious morphological modifications for their mode of life except perhaps in a slight lengthening of the antennae and hind tarsi and a slight enlargement of the eyes. Of the five species common in warehouses and granaries in Britain, probably four (2 *Gnathoncus*, 2 *Dendrophilus*) live out-of-doors normally in bird and animal nests.

A few have been found in caves but most of these are either accidental entrants or have only recently become cave-dwellers. One species, however, *Spelaeacritus anophthalmus*, Jeannel, is a true troglodyte and exhibits the typical morphological modifications found in cavernicolous beetles. Its antennae and legs are long, its head is nearly prognathous, eyes and hind wings are absent, and its elytra are fused together.

A large number of species in several unrelated sub-families regularly prey on the eggs, larvae, pupae, and, sometimes, adults of xylophagous beetles (Lyctids, Bostrychids, Anobiids, Ciids, Cerambycids, Scolytids, Platypodids). In this group of HISTERIDAE specialisation in the shape of the body has proceeded in two strikingly different directions. Those that live under loose bark of dead or dying trees are flattened, often very noticeably so, and more or less parallel-sided. Those that live in the burrows in the wood are narrow and cylindrical in shape. A few of the cylindrical forms belonging to the TERETRIINAE are predators of Lyctids and Bostrychids which attack the woodwork of warehouses.

The myrmecophiles form a large proportion of the HISTERIDAE, but comparatively few termitophiles are known. Amongst the myrmecophiles, every type of relationship from actively persecuted lodgers to well cared for guests (symphyles) is known. The adults and larvae of all species, however, feed chiefly on the eggs, larvae, or pupae of the ants. Some of the symphyles have on some part of the body clusters of golden-yellow hairs (trichomes) at the basis of which open glands which secrete substances much sought after by the ants. One species, *Eucurtia comata* (Blackb.), which lives with the Australian ant, *Ectatomma metallicum*, has on the elytra longer trichomes than any other myrmecophilous or termitophilous insect known. The larvae of some termitophilous Histerids are physogastric, *e.g.* the South African, *Monoplius pinguis*, Lewis, has specialised membranous areas on the abdomen from which exude secretions much liked by the termites.

Practically nothing is known of the natural enemies of Histerids. Their larvae are undoubtedly eaten by a number of different insects, and mites are commonly found attached to the adults, particularly to the propygidium and pygidium. Adults have been found in the stomachs of rooks and the Eastern Nightingale.

Economic Importance of Species associated with Stored Products.

Because of their exclusively predacious habits, the Histerids must be regarded as beneficial insects, but the amount of good that they do as predators of mite and insect pests is probably rarely if ever of any real importance. Most of the species breed only where the local relative humidities are high, and species of *Dendrophilus*, *Carcinops*, and *Gnathoncus* have usually only been found in large numbers in warehouses and mills where the local relative humidities were of the order of 90-95 per cent.

Five species, *viz.*: *Carcinops quattuordecimstriata* (Steph.), *Dendrophilus punctatus* (Hbst.), *D. xavieri*, Mars., *Gnathoncus nanus* (Scriba) and *G. nannetensis*, Mars., are relatively common indoors in Britain, and of these *C. quattuordecimstriata*, *D. punctatus*, and *G. nanus* have occasionally been found in considerable numbers, particularly in damp and heated waste grain.

Four species have been included in the keys but have not been described in the text for the reasons given below.

Teretrius picipes (F.) and *Teretriosoma americanum* (Lec.), like all members of the subfamily TERETRIINAE, normally inhabit the galleries of wood-boring beetles. Both are known to be predators of some of the Lyctids and Bostrychids that frequently attack building structures, and they may therefore occasionally be found indoors. *T. picipes* has been recorded with *Lyctus brunneus* (Steph.) by Fowler (1889); with *Sinoxylon sexdentatum* (Oliv.) by Ganglbauer (1899); and with *Lyctus linearis* (Goeze) by Bickhardt (1916). *T. americanum* has been recorded with *Lyctus planicollis*, Lec. (Reichardt, 1941).

Hister cadaverinus, Hoffm., and *H. merdarius,* Hoffm., have been found on several occasions during 1942-44 in Britain in mills and warehouses under dead rats and cats where they probably fed on maggots. Their status in relation to stored products is not yet clear, but *H. cadaverinus,* at least, is probably only a stray. The latter is very common out-of-doors in carrion, dung, compost-heaps, and accumulations of rotting vegetation. *H. merdarius* is found in similar situations but is rarer, and it has also often been found in the nests of various birds and owls and in pigeon-cotes.

KEY TO ADULTS.

1. Body cylindrical. Basal segment of antenna inserted in a socket which cuts into the lateral margin of the front. Mandibles small. Mesosternal disk with anterior middle produced into an emargination of the prosternal process. TERETRIINAE 2

— Body oval to nearly round. Basal segment of antenna inserted under the lateral margin of the front, the socket not cutting into the margin. Mandibles large. Mesosternal disk with anterior middle not produced but emarginate or nearly truncate..3

2. Prosternum with distinct median longitudinal striae. Length, 1·7-2·4 mm. Palaearctic..*Teretrius picipes* (Fabricius, 1792)

— Prosternum without median longitudinal striae or carinae. Length, 1·5-2·0 mm. Eastern United States...........*Teretriosoma americanum* (Leconte, 1859)

3. Prosternum with anterior part not or only very slightly bent ventrally and anterior margin usually truncate. Antennal club not divided into three parts by transverse sutures. SAPRININAE...4

— Prosternum with anterior third to one-half strongly bent ventrally, the process thus formed being often separated by a suture from caudal part; anterior margin strongly rounded and produced forwards. Antennal club with distinct transverse sutures 9

4. Head without lateral or frontal striae, only rarely with short and poorly developed supra-orbital striae. Elytron with three striae, including outer marginal, on vertical side. *Gnathoncus*..5

— Head with well developed lateral striae and sometimes with a distinct frontal stria. Elytron with not more than two striae, including outer marginal, on vertical side..7

5. Front tibia (fig. 32) with outer margin only feebly emarginate between spines. Abdomen without coarse punctures on first and fifth tergites, but fifth tergite with a single very large puncture on each side near spiracle. Male with anterior margin of tenth abdominal tergite (fig.36) truncate and caudal margin deeply, triangularly emarginate; genitalia (fig. 42) with dorsal channel more than half as long as parameres and with ventral basal margin of basal piece and parameres (fig. 45) truncate. Length, 1·8-3·0 mm. Europe....................*Gnathoncus punctator,* Reitter (1896)

— Front tibia (fig. 31) with outer margin deeply emarginate between spines. Abdomen with many coarse punctures on anterior half of first and fifth tergites. Male with anterior margin of tenth abdominal tergite (fig. 37) broadly, arcuately emarginate and caudal margin truncate or nearly so; genitalia (fig. 43) with dorsal channel much less than half as long as parameres and with ventral basal margin of basal piece and parameres (fig. 44) deeply emarginate at middle..6

6. Pygidium with punctures of basal half distinctly transverse and oblong or obovate. Male with apex of eighth abdominal sternite (fig. 35) pointed. Length, 1·5-3·0 mm. Palaearctic Region, Africa, Formosa. ....*Gnathoncus nanus* (Scriba, 1790)

— Pygidium with punctures of basal half round. Male with apex of eighth abdominal sternite (fig. 38) broadly rounded. Length, 2·4-3·8 mm. Palaearctic Region.....................*Gnathoncus nannetensis* (Marseul, 1862)

7. Length, 1·8-2·5 mm. Head with a well developed frontal stria. Antennal club with ventral side not depressed. Prosternum with median carinae converging anteriorly and ending some distance from anterior margin. Elytron without an apical stria; sutural stria complete and joined to third; third to sixth striae extending to apical third or fourth. Cuticle nearly always with a strong bronze or brassy lustre. Mediterranean Region, Caucasus, Turkestan. ....*Hypocacculus metallescens* (Erichson, 1834)

— Length, 4-10 mm. Head with or without a frontal stria. Antennal club with two or more large depressions on ventral surface. Prosternum with median carinae diverging anteriorly and extending to anterior margin. Elytron with a complete and distinct apical stria; sutural stria usually absent on basal region; third to sixth striae not or scarcely extending to apical two-fifths. Cuticle black or with a strong blue-green lustre, rarely with a feeble brassy lustre..8

8. Head without a frontal stria, *i. e.* lateral striae very widely interrupted across front. Cuticle black, rarely with a slight brassy lustre. Elytron with third stria as long as fourth. Prosternum with lateral carina joined to median at a point only slightly nearer to anterior margin than to coxal cavity; median carinae strongly diverging anteriorly. Hypomeron glabrous. Meso-metasternal sutural line coarsely and closely crenate. Male with a fringe of long, slender, curved setae on four basal segments of middle tarsi. Length, 4-7 mm. Palaearctic Region, N. India. ....*Saprinus semistriatus* (Scriba, 1790)

— Head with a complete or very nearly complete frontal stria. Cuticle nearly always with a distinct blue or blue-green metallic lustre. Elytron with third stria very much shorter than fourth and only present apically. Prosternum with lateral carina joined to median at a point about three times as far from coxal cavity as from anterior margin; median carinae only moderately diverging anteriorly. Hypomeron with long, erect setae. Meso-metasternal sutural line not crenate. Male without a fringe of long, slender, curved setae on four basal segments of middle tarsi. Length, 5-10 mm. Mediterranean Region, S. Europe, Iran, Caucasus, Turkestan.............................*Saprinus semipunctatus* (Fabricius, 1792)

9. Prothorax with cavity for the reception of the antennal club ventral and on the middle of the hypomeron, the cavity being broad and not sharply circumscribed. Anterior margin of prosternum on each side with a narrow and very deep emargination which receives the antennal funicle. DENDROPHILINAE 10

— Prothorax with cavity for the reception of the antennal club anterior, open in front, and more or less completely closed beneath by the sides of the prosternum, the cavity being deep and sharply circumscribed. Anterior margin of prosternum not emarginate. (The two species included here are 5·5 mm. or more long and both have two striae on each side of the pronotum parallel to the lateral margin.) HISTERINAE.....................13

10. Front tibia with inner margin straight or very nearly straight. *Dendrophilus.* 11

– Front tibia with inner margin distinctly curved. *Carcinops*........................12

11. Elytra with first and second striae absent, the second being only occasionally represented behind middle of disk by a row of punctures; dorsal half between suture and second stria with most punctures about two-thirds as large as apical punctures and separated by two to four diameters, the surface between them being microreticulate. Length, 2·6-4·0 mm. Europe, N. America.............................*Dendrophilus punctatus* (Herbst, 1792)

— Elytra with first and second striae usually distinct, sometimes with first obsolete or absent except at base; basal half between suture and second stria with punctures abruptly finer and much sparser than those of apical half, being about a fourth as coarse and usually separated by five to ten diameters and the surface between them is smooth and highly polished. Length, 2·5-3·7 mm. Japan, N. America, England. ....*Dendrophilus xavieri,* Marseul (1873)

12. Length, 1·6-2·7 mm. Elytron without a short stria between first and second striae. Propygidium nearly as long as pygidium; surface with fine and coarse punctures intermixed. Metasternal disk with inner lateral stria extending obliquely outwards and ending at a point considerably lateral and anterior to mesal margin of hind coxa. Abdomen with two striae on each side of disk of first sternite; extreme side of first sternite with a single stria near lateral margin. Male with clypeus not concave and frontal stria complete; male genitalia (fig. 53) with parameres only about one-fourth as long as basal piece. Cosmopolitan. ....*Carcinops quattuordecimstriata* (Stephens, 1832)

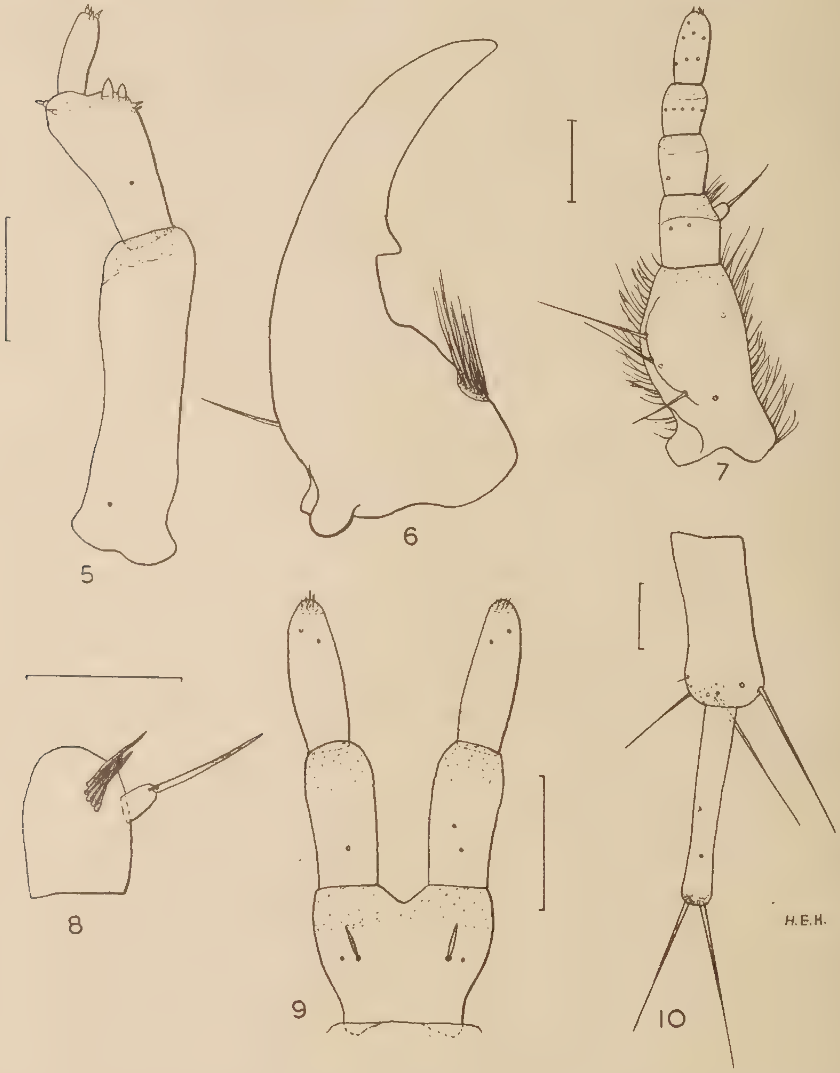
— Length, 1·4 mm. Elytron with a short supplementary stria on apical half between first and second striae. Propygidium less than half as long as pygidium; surface with fine punctures only. Metasternal disk with inner lateral stria nearly straight and ending at a point mesal to mesal margin of hind coxa. Abdomen with a single stria on each side of disk of first sternite; extreme side of first sternite with two parallel striae near lateral margin. Male with clypeus (and part of front of head?) strongly and broadly concave and frontal stria absent; male genitalia (fig. 54) with parameres more than half as long as basal piece. Egypt, Arabia..*Carcinops mayeti,* Marseul (1870)

13. Antennal club reddish with sutures between segments straight. Front tibia with four teeth on outer margin. Length, 5·5-7·0 mm. Europe, N. America..................................*Hister merdarius,* Hoffmann (1803)

— Antennal club greyish black with sutures between segments strongly curved. Front tibia with five or six teeth on outer margin. Length, 5·5-9·0 mm. Europe, Asia, Japan...........................*Hister cadaverinus,* Hoffmann (1803)

KEY TO LARVAE.

This key is based on third-instar larvae but will probably serve equally well for distinguishing between species represented by first- or second-instar larvae. First- and second-instar larvae of both *Hister cadaverinus,* Hoffm., and *Carcinops quattuordecimstriata* (Steph.) have been examined and found to differ only slightly from third-instar larvae, the chief difference being that the coronal and frontal sutures of the early stages are very distinct instead of absent or externally invisible.

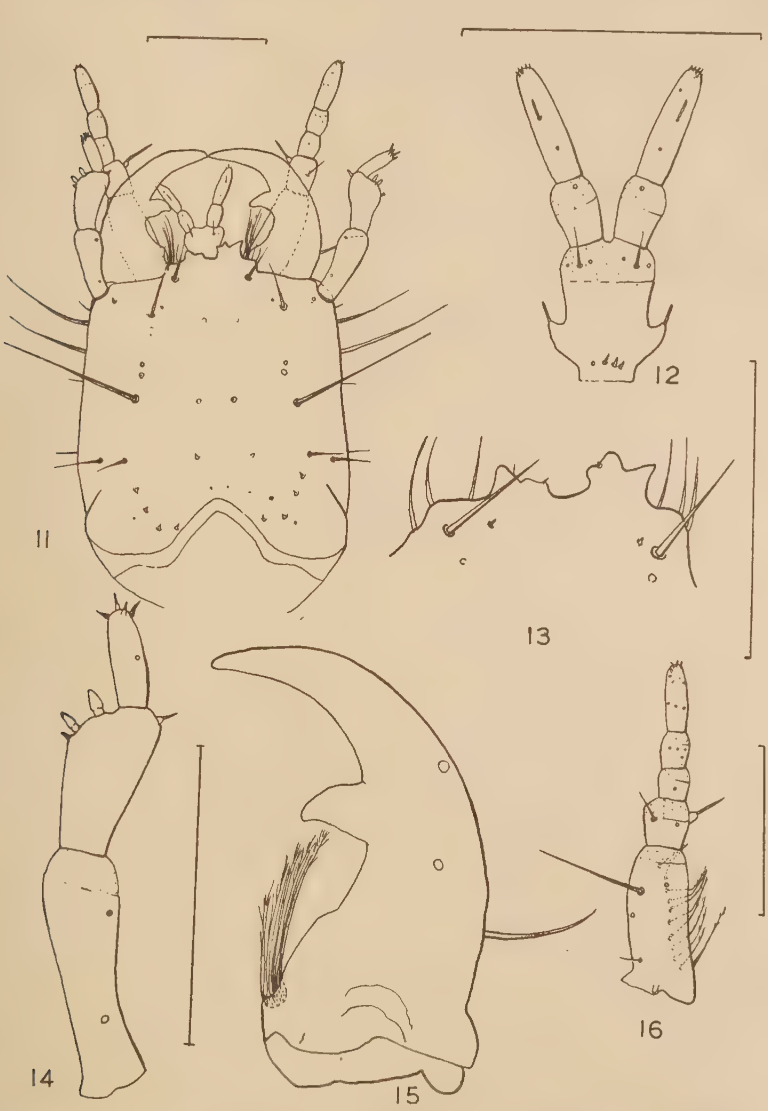


Figs. 5–10.—*Hister cadaverinus* Hoffm., third-instar larva. (5) Dorsal view of left antenna. (6) Ventral view of right mandible. (7) Ventral view of right maxilla. (8) Inner or dorsal view of left palpiger. (9) Ventral view of labium. (10) Dorsal view of urogomphus.

One species, *Teretrius picipes* (F.), and one genus, *Saprinus*, have been included in the key on the basis of characters given by Böving & Craighead (1931), but larvae of all other species dealt with have been examined by me. The larva of *Hister merdarius*, Hoffm., has been described by Paykull (1811, Monogr. Hist.: 22, pl. 1, f. 1) but not in sufficient detail to enable me to distinguish it satisfactorily from *H. cadaverinus*.

1. Maxillary palpi 5-segmented including palpiger and labial palpi 3-segmented, the apical segment of both the maxillary and labial palpi being much smaller than the preceding. Mandible without a tooth on cutting edge. TERETRIINAE...*Teretrius picipes* (F.)

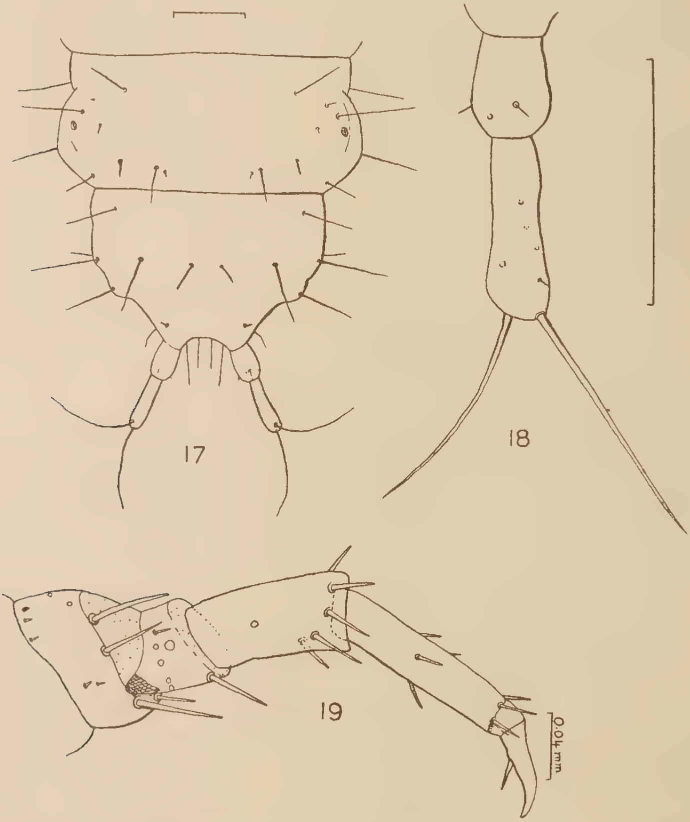
— Maxillary palpi (figs. 7, 16) 4-segmented including palpiger; labial palpi (figs. 9, 12) 2-segmented. Mandible (figs. 15, 27) with at least one large tooth on cutting edge...2



FIGS. 11–16.—*Carcinops quattuordecimstriata* (Steph.), second-instar larva. (11) Dorsal view of head. (12) Dorsal or inner view of labium. (13) Enlarged dorsal view of anterior margin of head. (14) Dorsal view of left antenna. (15) Dorsal view of right mandible. (16) Ventral view of right maxilla.

2. Pronotum with a well-marked longitudinal furrow on each side half way between median line and lateral margin. Abdomen with transverse rows of very short but distinct spines on first eight tergites and sternites. Tarsal claws (fig. 4) distinctly longer than tibio-tarsus and without setae. (Head distinctly broader than long and with a single ocellar lens on each side. Prementum (fig. 9) without a lateral sub-basal setose process. Urogomphi well sclerotised. Mature larva 15 mm. or more long.) ....*Hister cadaverinus,* Hoffm.

— Pronotum without longitudinal furrows. Abdomen without transverse rows of short spines on first eight tergites and sternites. Tarsal claws (fig. 19) distinctly shorter than tibio-tarsus and each with a ventral seta..........3



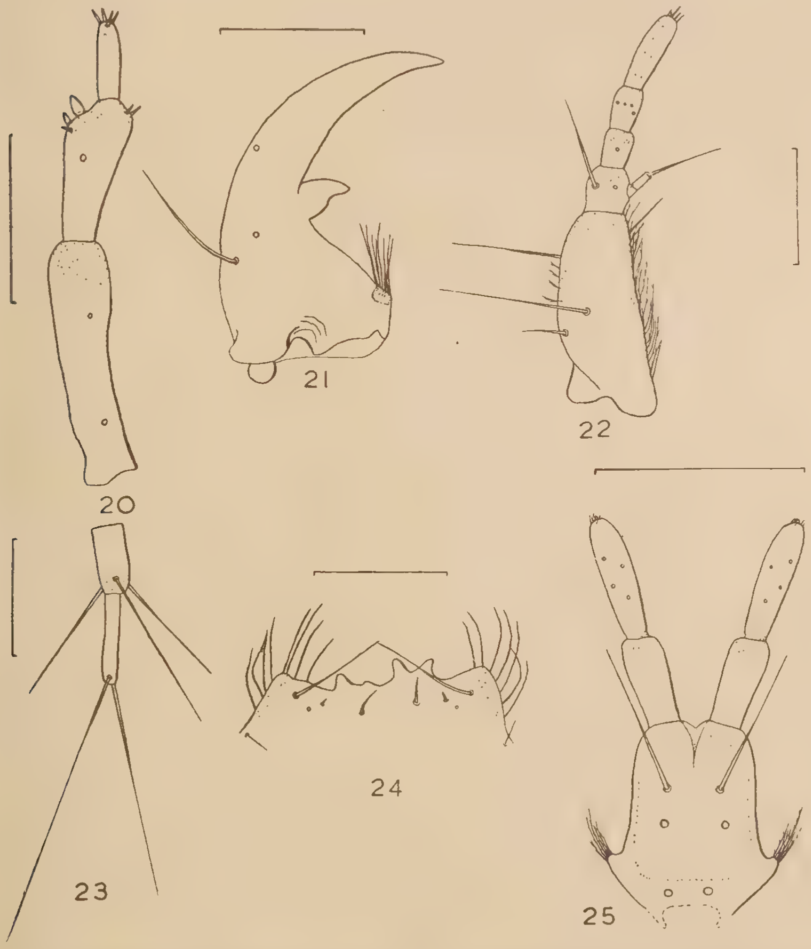
Figs. 17–19.—*Carcinops quattuordecimstriata* (Steph.), second-instar larva. (17) Dorsal view of eighth and ninth abdominal segments. (18) Inner dorsal view of urogomphus. (19) Anterior face of left middle leg.

3. Mandible (figs. 15, 21) with a single large tooth on cutting edge. Prementum (figs. 12, 25) on each side with a sub-basal process bearing one or more seta. Dendrophilinae..4

— Mandible with two large teeth on cutting edge or (fig. 27) with one large tooth and a small, obtusely rounded tooth. Prementum (fig. 28) without a lateral sub-basal setose process. Saprininae....................................5

4. Head (fig. 11) distinctly longer than broad; anterior middle margin with 3 + 3 teeth and anterior angle with only three long marginal setae (fig. 13); ocelli apparently absent; prementum (fig. 12) with a single seta on sub-basal lateral process. Urogomphus (fig. 18) with setae near apex of first segment very short, about a tenth as long as apical setae of second segment....................................*Carcinops quattuordecimstriata* (Steph.)

— Head no longer than broad; anterior middle margin with 2 + 2 teeth and anterior angle with seven or eight long marginal setae (fig. 24); ocelli represented on each side by a single poorly developed cuticular lens; prementum (fig. 25) with a brush of setae on sub-basal lateral process. Urogomphus (fig. 23) with setae near apex of first segment nearly as long as apical setae of second segment.............................*Dendrophilus punctatus* (Herbst)



Figs. 20–25.—*Dendrophilus punctatus* (Herbst). (20) Left dorsal view of antenna of second-instar larva. (21) Left dorsal view of mandible of same. (22) Ventral view of right maxilla of third-instar larva. (23) Dorsal view of left urogomphus of second-instar larva. (24) Dorsal view of anterior margin of head of third-instar larva. (25) Ventral view of labium of second-instar larva.

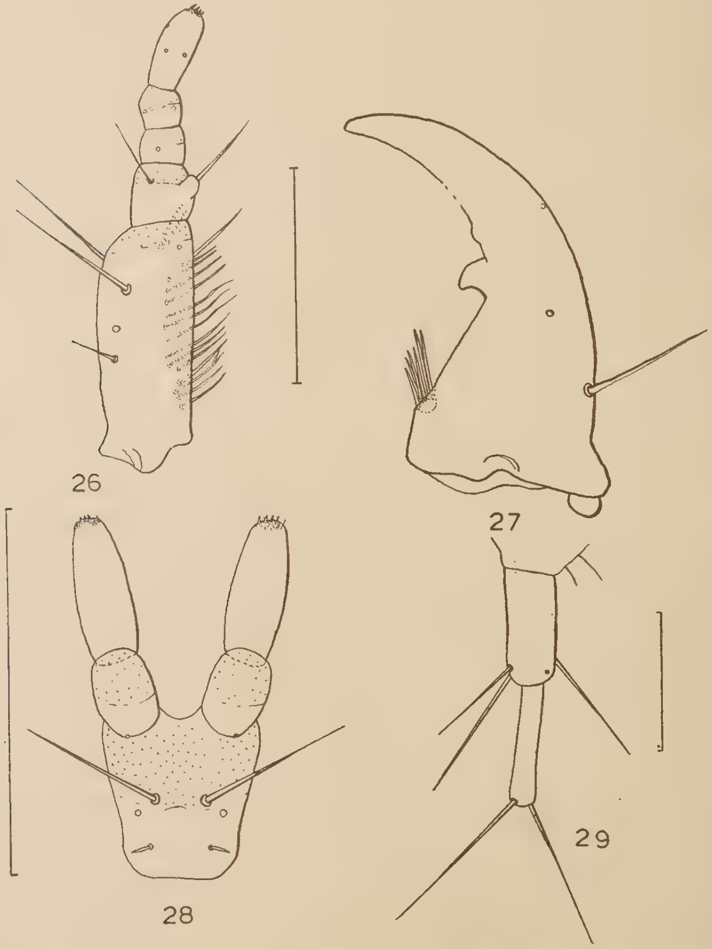
5. Mandible (fig. 27) with outer surface smooth; cutting edge with one large tooth plus one small and obtusely rounded tooth (Setae of abdomen very dark brown to nearly black)........................*Gnathoncus nanus* (Scriba)

— Mandible with outer surface irregularly sinuate near apex; cutting edge with anterior tooth nearly as long as posterior........................*Saprinus* spp.

Gnathoncus nanus (Scriba) (figs. 31, 35, 39).

1790. *Hister nanus,* Scriba, J. Lieb. Ent., **1,** p. 73, pl. v. f. 7, 7a, 7b.
1792. *Hister rotundatus,* Kugelann, in Schneider, N. Mag. Lieb. Ent., **3,** p. 304.
1798. *Hister punctatus,* Paykull, Fauna Suec., **1,** p. 49.
1862. *Gnathoncus punctulatus,* Thomson, Skand. Col., **4,** p. 242.

♂ : Length, 1·5-3·0 mm.; breadth, 1·2-2·0 mm. Body obovate to very broadly oval in outline and strongly convex. Cuticle strongly shining and black or very dark rufo-piceous; legs and antennae except club moderately dark rufo-piceous;



Figs. 26–29.—*Gnathoncus nanus* (Scriba), third-instar larva. (26) Ventral view of right maxilla. (27) Dorsal view of right mandible. (28) Ventral view of labium. (29) Inner dorsal view of left urogomphus.

antennal club paler reddish and densely clothed with fine testaceous hairs. *Head* with marginal striae absent, but occasionally with a shallow, indistinct supra-orbital stria. Punctures on middle round, shallow, indistinctly umbellicate (mag. × 100), slightly coarser than facets of eyes, and separated by one and a half to three diameters. Clypeus with punctures slightly denser. Surface between punctures smooth or with an occasional microscopic puncture. *Pronotum* with apical stria complete and lateral stria on each side extending very nearly to base. Surface of middle of disk with round or oval, occasionally umbellicate punctures about as coarse as those of head and usually separated by two to four diameters; towards sides punctures become coarser and denser so that a short distance from lateral margin they are half again to twice as coarse as those of middle of disk, slightly deeper, and are separated by half of one to two diameters; immediately before lateral margin the punctures are nearly as fine as those of middle of disk; base with a single or double, usually rather indistinct, transverse row of punctures which are nearly as coarse as those of sides. Surface between punctures smooth and with an occasional microscopic puncture. *Elytra* with apical stria extending to suture but often fine, shallow, and rather indistinct. Sutural stria confined to basal region or extending to slightly beyond middle, but if long often represented more by a row of punctures than by a distinct impressed line; beyond basal third slightly diverging from suture towards apex and near base also diverging from suture.

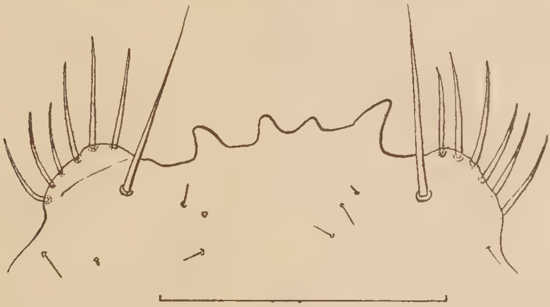


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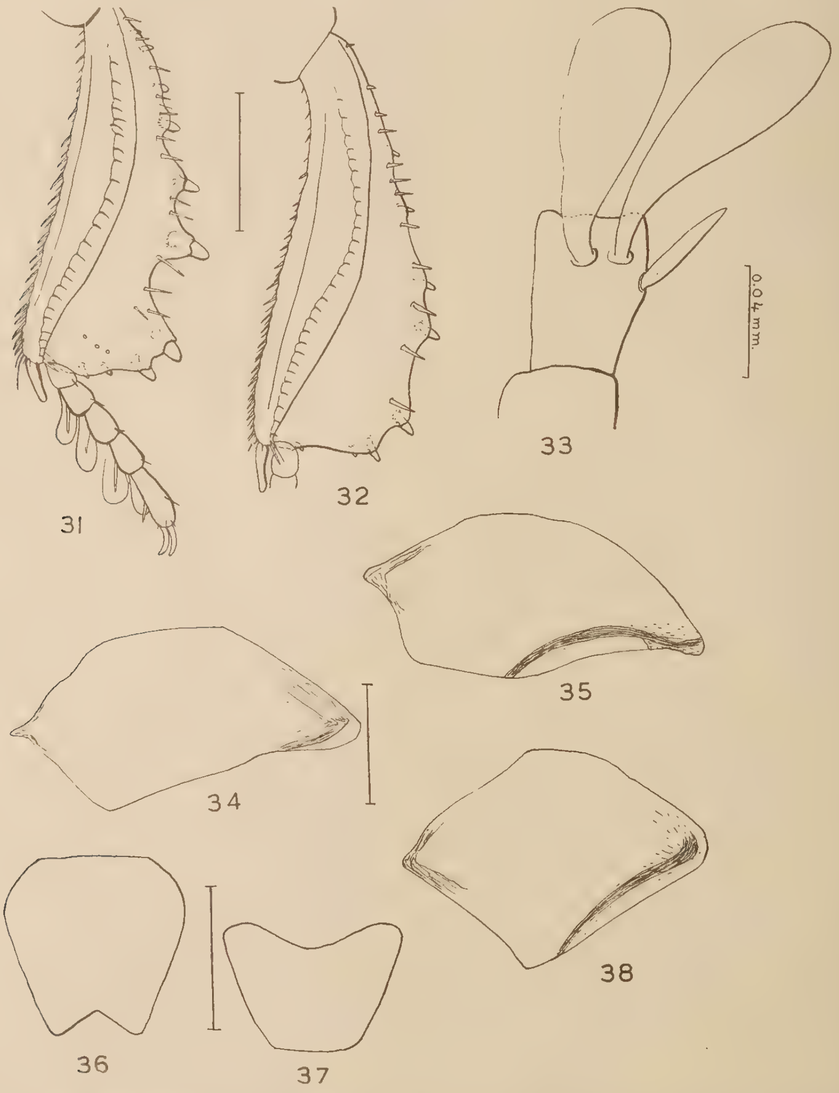
FIG. 30. *Gnathoncus nanus* (Scriba), anterior margin of head of third-instar larva.

Second stria only represented by a short, curved, transverse line at base. Third to fifth stria extending from base, where each is curved mesally, to about middle or slightly beyond middle. Sixth stria usually extending to about apical third but much finer beyond middle. Humeral stria confined to basal third or fourth, very finely to moderately coarsely impressed, and sometimes crossed by a number of fine, oblique rugae so that it appears to be irregular. Subhumeral stria coarse and usually extending from basal two-fifths to apical two-fifths but sometimes longer and nearly reaching humeral stria. Strial punctures close and about as coarse as those along base of pronotum. Surface of apical half or three-fifths with broadly oval, deep punctures which are about as coarse as those of extreme base of pronotum and are separated by one to two diameters; surface of basal half or two-fifths slightly more finely and distinctly more sparsely punctate than middle of pronotal disk; extreme apex of elytra (in region of apical stria) with the punctures finer than elsewhere on apical region and with surface between punctures finely, lightly, and longitudinally rugose or nearly smooth. Surface between all discal elytral punctures smooth or nearly so. *Propygidium* with punctures of caudal half round or transversely oval, as large as those before apical elytral stria, and seldom separated by as much as one diameter. Surface between punctures with a lightly impressed but distinct series of fine and irregularly transverse lines which are often reticulate, these lines being more heavily impressed on basal half which is also more finely and much more sparsely punctate. *Pygidium* with basal punctures as coarse or coarser than caudal ones of propygidium, slightly sparser, and subquadrate or semi-elliptical but always with nearly all distinctly transverse; on apex these punctures are sparser and much finer; the coarse pygidial punctures often have a central microscopic puncture, *i.e.*, they are often umbellicate.



FIGS. 31–38. *Gnathoncus* spp. (31) Front tibia of *G. nanus* (Scriba). (32) Same of *G. punctator* Reitt. (33) Ventral view of third segment of front tarsus of ♂ of *G. nannetensis* (Mars.). There is often only one flat seta on segments one to four, but there are sometimes two setae on first segment and only one on the second to fourth inclusive. (34) Eighth abdominal sternite of male of *G. punctator*. (35) Same of *G. nanus*. (36) Tenth abdominal tergite of male of *G. punctator*. (37) Same of *G. nannetensis*. (38) Eighth abdominal sternite of male of *G. nannetensis*.

Surface between punctures smooth or nearly so. *Prosternum* with median carinae joined or nearly joined anteriorly; lateral carinae prominent and joining median carinae at a point slightly nearer to front coxal cavity than to anterior margin. Mesosternal disk with complete and coarse apical and lateral striae; near caudal margin with a coarsely crenate line which, except at sides, is slightly anterior to meso-metasternal sutural line; surface coarsely and sparsely punctate. Metasternal disk flat to feebly concave and surface coarsely and sparsely punctate; lateral discal stria extending caudally and outwards nearly to hind coxa.

♀: Externally similar to male but without large, broad, flat setae on four basal segments of front tarsi and with the metasternal disk feebly convex instead of flat or feebly concave.

Distribution: Palaearctic Region, Africa, Formosa.

Habits: Donisthorpe (1897) records it in a London granary; Gerhard (1909) in a pigeon-cote in Germany; Joy (1909) in a starling's nest in Britain; Auzat (1917) in France in hen-houses, birds' nests, and carrion, especially dead birds; Donisthorpe (1939) in Windsor Forest on bones and in a crow's nest; and Reichardt (1941) records it in the U.S.S.R. on carrion, especially dead birds, occasionally in dung and rotting vegetation, frequently in hen-houses, dove-cotes, and old nests of squirrels, hoopoes, owls, starlings, ravens, etc.

During 1942-44 specimens were found in granaries at Burnham, Bucks and N. Belfast, warehouses at Norwich and London, and large numbers in waste grain in the basement of a London flour mill.

Gnathoncus nannetensis (Marseul) (figs. 33, 37-38, 40, 43-44).

1803. *Hister rotundatus* (var. a), Hoffmann, Ent. Hefte, **1**, p. 87, pl. 1, f. 10.
1862. *Saprinus nannetensis*, Marseul, Ann. Soc. ent. Fr., (4) **2**, p. 499, pl. 13, f. 2.

♂: Length, 2·4-3·8 mm.; breadth, 1·6-2·4 mm. Very similar to *G. nanus* but differs in having the pygidial punctures round and never transverse instead of distinctly transverse, and in having the apex of the eighth abdominal sternite (fig. 38), which is lateral, broadly rounded instead of moderately pointed, this sternite being a little longer than broad in *G. nannetensis* and nearly twice as long as broad in *G. nanus*. *G. nannetensis* is on the average a distinctly larger species; the sutural elytral stria is more often confined to the basal region; the extreme apex of the elytra is frequently much more coarsely and longitudinally rugose than in any specimens of *G. nanus* seen; the surface between the pygidial punctures is often distinctly but very finely alutaceous, whereas in *G. nanus* the surface between the pygidial punctures is very rarely alutaceous; and the prosternal striae often end anteriorly in a deep pit.

♀: Differs from the male in not having broad, flat, ventral setae on the four basal segments of the front tarsi and in having the metasternal disk convex instead of flat or feebly concave.

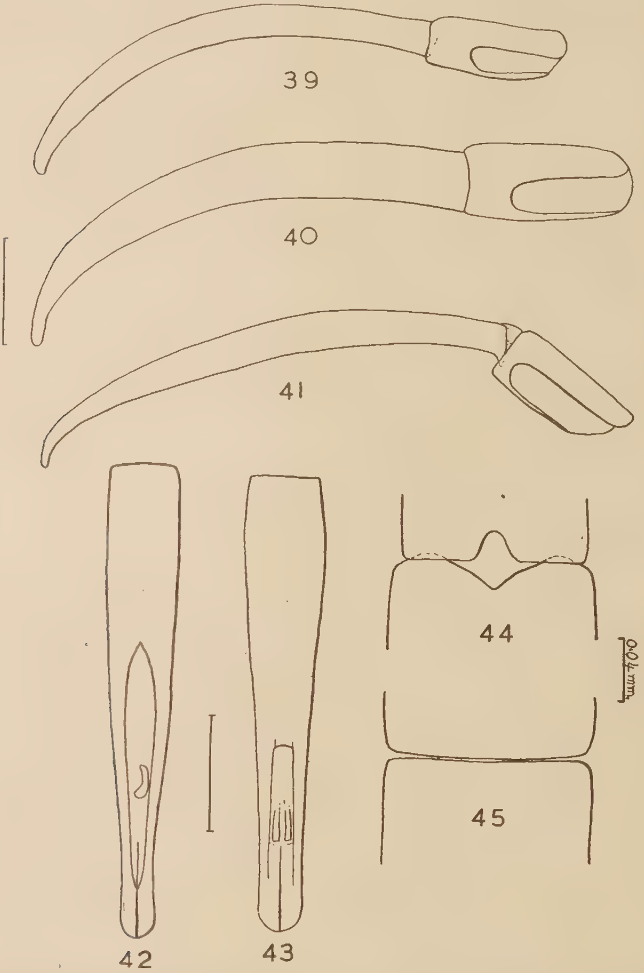
Distribution: Palaearctic Region.

Habits: Walker (1916b) records it in a granary at Cothill, Berks; Auzat (1917) in France in hen-houses, birds' nests, and carrion, especially dead birds; Donisthorpe (1939) in Windsor Forest in a bird's nest, on old bones, and in a dead bird. According to Reichardt (1941) its habits are similar to those of *G. nanus* (Scriba). It is found in carrion, especially dead birds, and more rarely in dung and rotting vegetation. It is common in hen-houses, dove-cotes, old nests of squirrels and in nests of such birds as hoopoes, owls, starlings, and ravens.

Gnathoncus punctator, Reitter (figs. 32, 34, 36, 41-42, 45).

1896. *Gnathoncus punctator,* Reitter, Ent. Nachr., **22,** p. 307.
1907. *Gnathoncus nidicola,* Joy, Ent. Rec., **19,** p. 134, pl. 6, f. 2.
1918. *Gnathoncus nidicola* var. *auzati,* Pic, Echange, **34,** p. 9.

♂: Length, 1·8-3·0 mm.; breadth, 1·6-2·2 mm. Very similar to *G. nanus* and *G. nannetensis* from both of which it differs as follows: (1) the outer margin of the front tibiae is much less deeply emarginate (*cf.* figs. 32 and 31); (2) the first abdominal tergite has no coarse punctures instead of an anterior belt of very coarse punctures; (3) the fifth abdominal tergite has only a single large puncture on each side near spiracle instead of a complete, transverse, anterior belt of coarse, close



Figs. 39–45. Male genitalia of *Gnathoncus* spp. (39) Lateral view of *G. nanus* (Scriba). (40) Same of *G. nannetensis* (Mars.). (41) Same of *G. punctator,* Reitt. (42) Dorsal view of *G. punctator.* (43) Same of *G. nannetensis.* (44) Ventral view of base of parameres and basal piece of *G. nannetensis.* (45) Same of *G. punctator.*

punctures; (4) the tenth abdominal tergite is truncate at base and deeply, triangularly emarginate at apex (fig. 36), whereas in *G. nanus* and *G. nannetensis* (fig. 37) the base of this tergite is broadly, arcuately emarginate and its apex is truncate or nearly so; (5) the male genitalia have the parameres much less curved (*cf.* figs. 41 and 40); (6) the dorsal channel occupies much more than half instead of much less than half of the length of the parameres (*cf.* figs. 42 and 43); and (7) the ventral base of both the parameres and the basal piece is truncate instead of deeply emarginate at middle (*cf.* figs. 45 and 44). In addition to the differences listed above, the punctures of the pygidium are somewhat different, being much less transverse than in *G. nanus* and more strongly umbellicate than in *G. nannetensis.* Many of the umbellicate punctures are half-moon shaped with the caudal middle part open and joined to the raised centre, and the surface between the punctures is nearly always distinctly microreticulate. The sutural stria is confined to the extreme basal region in all specimens seen. The apex of the elytra is usually more strongly rugose than in *G. nannetensis,* and the coarse punctures often extend to the base of the elytra in the interval between the fifth and sixth striae.

♀: Differs from male in having the metasternal disk feebly convex instead of feebly concave in anterior half and in not having the large, flat, ventral setae of the four basal segments of the front tarsi.

Distribution: Europe, Caucasus, Turkmen.

Habits: In Britain it has been found in the nests of various kinds of birds and on one occasion in straw in a shed (Joy, 1907, 1909). Auzat (1917) records it in hen-houses and in birds' nests in France. Donisthorpe (1939) records it in Windsor Forest under a dead pigeon, on bones, and abundant in birds' nests. According to Reichardt (1941) it is found in the U.S.S.R. almost exclusively in birds' nests and only rarely in hen-houses. I have seen a few specimens which were found in March, 1942, in a granary in Gloucester.

Hypocacculus metallescens (Erichson) (fig. 46).

1834. *Saprinus metallescens,* Erichson, in Klug, Jahrb. Insectenk., **1**, p. 192.
1867. *Saprinus geminatus,* Wollaston, Col. Hesperid., p. 86.
1876. *Saprinus arachidarum,* Marseul, Abeille, Paris, **16**, p. 39.

♂: Length, 1·8-2·5 mm.; breadth, 1·3-1·7 mm. Body broadly oval and strongly convex. Cuticle very strongly shining and black or nearly so with a strong bronze or brassy lustre, but a few specimens—probably only those recently emerged—are dark rufo-piceous and lack the metallic lustre; antennae dark rufo-piceous with club rufo-testaceous; legs dark reddish brown. *Head* with frontal stria arcuate and complete across front; stria complete at base but on sides sometimes interrupted on supra-orbital region. Surface with punctures slightly coarser than facets of eyes and rather evenly distributed, being separated by one to two diameters; surface between punctures smooth or nearly so. Clypeus punctate like head but near anterior margin more densely so. Labrum with a broad, transverse impression. Pronotum with marginal stria of apex and sides complete and at front angles much further from edge than elsewhere. Surface of disk with punctures as fine as those of head but separated by three to five or more diameters; on each side about two-thirds of distance to lateral margin these punctures become abruptly coarser and denser so that a short distance before lateral margin they are about four or five times as coarse and are separated by one-fourth to three-fourths (on apical half) of a diameter or (basal half) one or two diameters; on a belt adjacent to lateral margin they are nearly as fine as on middle of disk but are denser; base with two rather regular rows of punctures which are nearly as coarse as those of sublateral apical belt; middle of base with three transverse rows of coarse punctures;

surface between pronotal punctures everywhere smooth or nearly so. *Elytra* punctate and striate as shown in fig. 46. *Propygidium* one-third as long as pygidium and caudal half with round or slightly oval punctures which are as coarse and dense as those near apex of elytra; surface between punctures very finely, transversely alutaceous. *Pygidium* with round or very slightly transversely oval punctures which are as coarse as those of caudal half of propygidium, are occasionally umbellicate, and are usually separated by one to nearly two diameters; on apex these punctures are slightly sparser and distinctly finer; surface between punctures scarcely noticeably, transversely microreticulate but on apical half the surface is smooth or nearly so. *Prosternum* with median striae (or carinae) widely separated on apex of process and strongly converging anteriorly but nearly parallel on anterior half where they end some distance from anterior margin; carinae in front of anterior coxae more prominent than median prosternal carinae, to which they are not joined, and joined together to form a straight line along anterior margin. Mesosternal disk with anterior margin nearly truncate; thickly margined at apex and sides; surface with round, moderately coarse punctures which are separated by one to three diameters and are only slightly sparser on middle. Metasternum with lateral stria extending caudally and outwards nearly to hind coxa: disk very sparsely and finely punctate but with a few coarser and denser punctures at sides, and on each side before hind coxa with a small area which is as coarsely and densely punctate as propygidium. Abdomen with lateral discal stria of first sternite extending from base to near caudal margin in an arcuate curve.

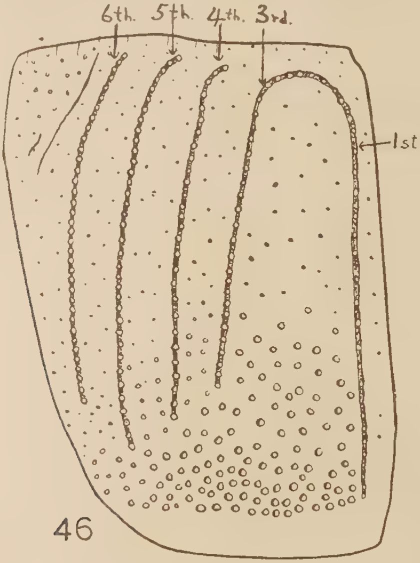


FIG. 46. Elytra of *Hypocacculus metallescens* (Er.).

♀ : Externally similar to male.

Distribution: Mediterranean Region, Caucasus, Turkestan.

Habits: It has been found in France in stored ground-nuts (Marseul, 1876) and in Egypt in small numbers in bran (Willcocks, 1925) and in warehouses in débris under mats, in mills, and in flour (Zacher, 1940). According to Reichardt (1941), it is found out of doors in dung.

Saprinus semistriatus (Scriba) (fig. 47).

1790. *Hister semistriatus,* Scriba, J. Leib. Ent., **1,** p. 72.
1798. *Hister semipunctatus,* Paykull, Fauna Suec., **1,** p. 45.
1801. *Hister nitidulus,* Fabricius, Syst. Eleuth., **1,** p. 85.

♂: Length, 4-7 mm.; breadth, 3·0-4·5 mm. Body broadly oval and strongly convex. Cuticle very strongly shining and black but occasionally with a scarcely noticeable brassy lustre; tarsi and funicle of antenna dark rufo-piceous. *Head* with marginal stria well developed but absent on middle two-thirds of front. Surface on each side above eye with a large area set with round to oval punctures which are about four times as coarse as facets of eyes and are separated by less than one to one diameter; clypeus slightly more finely and sparsely punctate and middle of front with punctures one-half as coarse and separated by two to four diameters; surface between punctures with very sparse, microscopic punctures. *Pronotum* with apical and lateral striae coarse and complete. Surface of most of disk with two sizes of microscopic punctures separated by about four to ten diameters; on each side near lateral margin with a broad belt of very dense punctures which are often twice as coarse as supra-orbital punctures of head, this belt extending slightly mesally near apex as shown in fig. 47; base with a narrow belt of similar coarse and dense punctures. *Elytra* with apical stria complete, distinct, and joined to sutural which is absent on basal third or two-fifths and is sometimes broadly interrupted or indistinct on much of apical two-thirds; third to sixth striae as shown in fig. 47; these dorsal striae vary considerably and may be broadly interrupted at one or more points, the fourth and fifth are usually not joined at base, and the third and fourth may run into each other on basal fourth or fifth of elytra. Strial punctures are coarse, dense, deep, and more or less round. Apical two-fifths of elytra (fig. 47) is punctate like striae with the punctures usually separated by one to three diameters; basal three-fifths microscopically and very sparsely punctate;

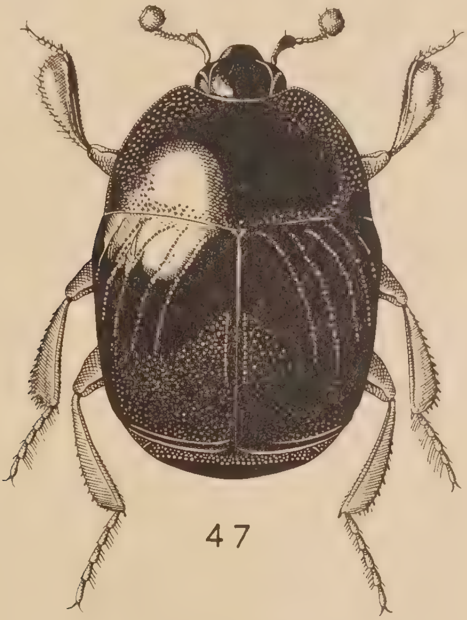


FIG. 47. *Saprinus semistriatus* (Scriba).

intervals between fifth and sixth striae often coarsely punctate nearly to base and often with numerous oblique, deeply impressed lines. *Propygidium* on caudal one-half or two-thirds with punctures very slightly coarser than those of apex of elytra and seldom separated by as much as one diameter; surface between punctures with a lightly impressed, transverse, alutaceous microsculpture. *Pygidium* sculptured like caudal part of propygidium but on apex with punctures finer and sparser; some specimens with a complete or nearly complete, narrow, median longitudinal line which is impunctate. *Prosternum* with median carinae widely diverging anteriorly and attaining anterior margin; lateral carinae on each side joined to median at a point very slightly nearer to anterior margin than to coxal cavity. Hypomeron not pubescent. Mesosternal disk with punctures as coarse as those of elytral apex but usually separated by two to four diameters; meso-metasternal suture very coarsely crenate. Metasternal disk broadly, feebly, longitudinally concave. Front tarsi with a long, flat, broadly lanceolate, testaceous seta on ventral apex of each of four basal segments; middle tarsi with a fringe of five or six very long (as long as fifth tarsal segment), moderately slender, close, curved, testaceous setae on each of four basal segments, these setae arising from inner ventral margin.

♀: Differs from male as follows: (1) the middle of the metasternal disk is only slightly concave on caudal third; (2) the four basal segments of the front tarsi have stout ventral spines but no long, flat, lanceolate setae; and (3) the four basal segments of the middle tarsi have no fringe of very long, slender, curved setae.

Distribution: Palaearctic Region, N. India.

Habits: Sacharov (1921) records it at Astrachan where it was found to be a predator on the larvae of *Dermestes lardarius*, L., and *D. frischii*, Kug., in stores of air-dried and smoked fish. Zacher (1927) records it attacking fresh meat and occurring in granaries in Germany. According to Reichardt (1941), it is very common in carrion but less common in dung, and it is also found in hamster burrows and in the flowers of *Dracunculus* and *Amorphophallus*.

Saprinus semipunctatus (Fabricius).

1792. *Hister semipunctatus*, Fabricius, Ent. Syst., **1**, p. 73.

♂: Length, 5-10 mm.; breadth, 4·6 mm. Body broadly oval and strongly convex. Cuticle strongly shining; black and nearly always with a distinct blue-green or blue metallic lustre; funicle of antennae, tarsi, and sometimes also tibiae dark rufopiceous. *Head* with marginal stria complete or nearly complete and rather strongly arcuate across front. Surface on each side near eye with a group of very coarse, dense, oval punctures; surface between these with punctures about half as coarse and usually separated by one to two diameters though punctures are denser on clypeus; surface between coarse punctures sparsely, microscopically punctate and smooth or (usually base and clypeus) finely, transversely alutaceous; sides of clypeus longitudinally alutaceous. *Pronotum* with apical and lateral striae coarse and complete, but lateral striae ending a short distance before base. Surface of most of disk very sparsely punctate with two distinct kinds of microscopic punctures, the larger being twice as coarse as the smaller; on each side near lateral margin with a broad belt of very coarse punctures, this belt extending mesally near apex and near base; on middle of belt the punctures are nearly twice as large as supra-orbital ones of head and are contiguous to separated by half of one diameter; basal belt of coarse punctures broadly interrupted at middle of base. *Elytra* with apical stria deep, complete, and joined to sutural which extends to basal third or fourth; third stria very short and extending from about middle of elytra to basal third; fourth stria extending from near base to about middle; fifth is slightly shorter than fourth; and sixth is confined to basal third, is usually rather irregular, and is crossed by a number of fine, short, deeply impressed lines. Surface of apical half at sides and apical fourth or fifth near suture with round punctures which are about as coarse as supra-orbital ones of head and are separated by one to three diameters; interval between fifth and sixth stria usually similarly but more sparsely punctate as well as coarsely, obliquely rugose; surface elsewhere with very sparse microscopic punctures which are finer than those present between the coarse apical punctures. Striae sparsely and irregularly crenate with coarse punctures; sutural stria more finely and indistinctly crenate than other dorsal striae. *Propygidium* on caudal three-fourths with rather shallow, round or oval punctures which are as coarse as coarser ones of elytra and are nearly contiguous to occasionally separated by more than one diameter. Surface between punctures microscopically and transversely alutaceous. *Pygidium* sculptured like propygidium but with punctures very slightly deeper and sparser; some specimens with an indistinct, median longitudinal, impunctate line. *Prosternum* with median carinae nearly parallel but moderately diverging anteriorly beyond point at which they are joined to lateral carinae; lateral carinae joined to median at a point which is three times as far from coxal cavity as from anterior margin. Hypomeron with numerous long, erect testaceous setae. Mesosternal disk finely, sparsely punctate but with a few coarse and dense punctures at sides and along caudal margin; meso-metasternal sutural line fine and not crenate. Metasternal disk on middle broadly and moderately shallowly concave for all of its length. Front tarsi with a long, flat, lanceolate, testaceous seta on ventral apex of each of four basal segments.

♀ : Differs from male in having no long and lanceolate ventral setae on four basal segments of front tarsi.

Comparative Notes: Its larger size, blue or blue-green metallic lustre, pubescent hypomera, and non-crenate meso-metasternal suture will serve to distinguish it from *S. semistriatus* (Scriba).

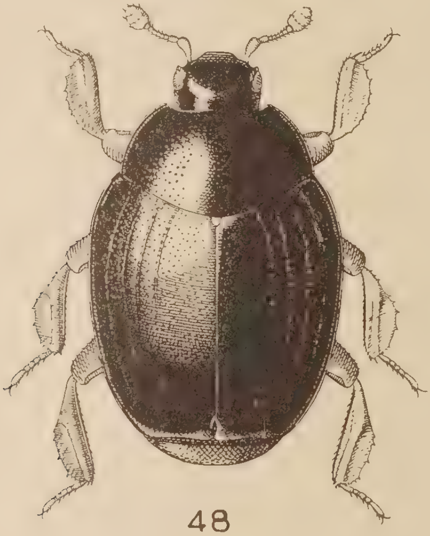
Distribution: Mediterranean Region, S. Europe, Iran, Caucasus, Turkestan, Turkmen.

Habits: Sacharov (1921) records it with *S. semistriatus* at Astrachan where it was found to be a predator of the larvae of *Dermestes lardarius*, L., and *D. frischii*, Kug., in stores of air-dried and smoked fish. According to Reichardt (1941), it is usually found on dead animals, particularly large ones, and has been found in hamster burrows and in the flowers of *Dracunculus*.

Dendrophilus punctatus (Herbst) (fig. 48).

1792. *Hister punctatus*, Herbst, in Jablonsky, Nat. Ins. (Käf.), **4**, p. 41, pl. 36, f. 5.
1775. *Hister pygmaeus*, Fabricius, Syst. Ent., **1**, p. 53.
1798. *Hister corticalis*, Paykull, Fauna Suec., **1**, p. 50.
1825. *Hister punctulatus*, Say, J. Acad. nat. Sci. Philad., **5**, p. 45.
1830. *Dendrophilus cooperi*, Stephens, Ill. Brit. Ent., **3**, p. 159.

♂: Length, 2·6-4·0 mm.; breadth, 1·8-2·3 mm. Body broadly oval and strongly convex. Cuticle moderately strongly shining and black with tarsi and segments 2-8 of antennae dark rufo-piceous; tibiae sometimes dark rufo-piceous; antennal club brown and densely clothed with fine, testaceous hairs. *Head* with round punctures which are about as coarse as facets of eyes and are usually separated by one diameter; head also with a few finer (about two-thirds as coarse) punctures. Surface between punctures with a fine, indistinct (mag. × 75), reticulate microsculpture. *Pronotum* at broadest point, which is at base, nearly twice as broad as long (65:38) and base twice as broad as apex (65:32). Sides evenly arcuate; apex and sides completely margined, base not margined. Disk with round or feebly oval punctures which are very slightly coarser than those of head and are separated by one and a half to two diameters, rarely more; disk also with sparse punctures about half as large as the latter; towards sides and base punctures gradually become coarser and denser so that near hind angles they are almost half again as large as those of middle of disk and are separated by half of one to one diameter, but very near lateral margins they are nearly as fine as on middle of disk. Surface between punctures with a reticulate microsculpture like that of head but at sides of pronotum this microsculpture is more evident. *Elytra* with first two striae absent; third and fourth well impressed and extending to slightly beyond middle; fifth and sixth slightly more strongly impressed and extending to apical third or even apical fifth but indistinct beyond basal three-fifths; seventh (outer marginal stria) distinctly more deeply impressed than others, complete or nearly so, and nearly contiguous at both base and apex to inner epipleural stria; oblique humeral stria shallow and indistinct; apical half of elytra sometimes with a scarcely visible stria between sixth and seventh striae. Punctures of middle of disk sparser and slightly finer than those of middle of pronotal disk; elsewhere with punctures slightly coarser and as dense as those of basal sides of pronotum; near apex surface is sometimes very feebly, longitudinally rugose. *Propygidium* one-fourth as long as pygidium (8 : 33) and exposed apical half with round punctures which are about as coarse as those of elytral apex and are separated by one-fourth to two-thirds of one diameter; basal half, which is usually concealed by elytra, with sparser and much finer punctures. Surface between punctures with a fine reticulate microsculpture. *Pygidium* feebly convex or nearly flat, but sometimes with a feebly convex median longitudinal line on basal two-thirds. Surface sculptured like caudal half of propygidium but with punctures half again to twice as coarse; apex with punctures much shallower and as fine as those of middle pronotal disk. *Prosternum* with caudal margin of process broadly, strongly, evenly rounded. Carina in front of anterior coxa prominent, nearly straight, and not extending further anteriorly than prosternal carinae. Mesosternum with apex shallowly, arcuately emarginate and without an apical marginal line; side of disk with a distinct and nearly complete marginal line which anteriorly extends slightly mesally;



[Fig. 48. *Dendrophilus punctatus* (Herbst).

caudal marginal line with numerous deep and rather irregular crenations. Surface sculptured like middle basal sides of pronotum. Metasternum with lateral stria on each side extending caudally and outwards in a nearly straight line to a point near middle of episternum. Disk very finely and sparsely punctate; sides with punctures as coarse and nearly as dense as those of pygidium.

♀: Externally similar to male.

Comparative Notes: This species is very close to *D. xavieri*, Marsaul, but may be distinguished by the absence of the first and second elytral striae and the punctures of the elytra which only gradually become slightly finer towards the middle of the disk instead of being abruptly finer on the basal half.

D. championi Lewis (1886) from Turkey, which is considered by some authors to be a synonym of *D. punctatus*, is a good species. It is striate like *D. xavieri* and punctate like *D. punctatus* but much more coarsely so.

Distribution: Europe, N. America.

Habits: In a hornet's nest in Germany (Erné, 1877); occasionally in pigeon-houses in France (des Gozis & Fauvel, 1886); in dead animals, in rotten wood, and in the nests of *Acanthomyops fuliginosus* in Britain (Fowler, 1889); in a London granary (Donisthorpe, 1897); at sap of tree and in the nests of *Acanthomyops fuliginosus* in Germany (Ganglbauer, 1899); in nests of starlings, daws, owls, and woodpeckers in Germany where it is the most regular beetle inhabitant of birds' nests (Gerhard, 1909); in a cellar in a granary, in bird and owl nests, in a bone heap, and in the nests of *Formica rufa* in Britain (Fowler & Donisthorpe, 1913); in a bone works at Acton Bridge, Cheshire (Walker, 1916a); in birds' nests in France (Auzat, 1917); in a granary at Cothill, Berks (Walker, 1916b); in a starling's nest in Sussex (Bennett, 1915); under floors of granaries and railway sheds in the U.S.S.R. (Zvierezomb-Zubovskii, 1917); in hornet nests in Europe (Bickhardt & Wasmann, 1925); in owl's castings and in a sack-heap on the Isle of Sheppey (Walker, 1932); frequently in waste grain in flour mill basements in the U.S.A. (Cotton & Good, 1937); in Windsor Forest in loose hay, straw-refuse, in company with *Acanthomyops brunneus*, in squirrels' nests, and in some numbers in birds' nests (Donisthorpe, 1939); in flour mills in various parts of Eastern and Central U.S.A. (Ross, 1940); and in a woodpecker's nest in Surrey (Duffy, 1944).

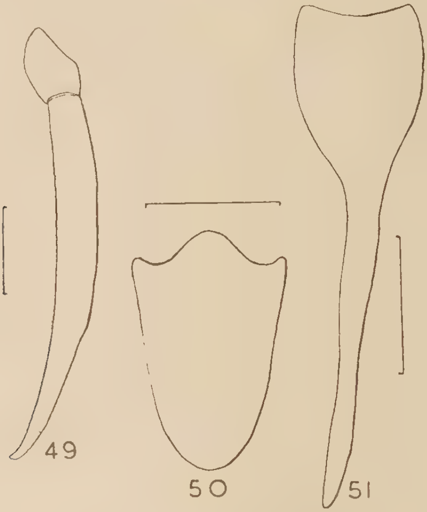
During 1943 it was found in warehouses, granaries, and mills in London, Bristol, and Liverpool.

Dendrophilus xavieri, Marseul (figs. 49-51).

1873. *Dendrophilus xavieri,* Marseul, Ann. Soc. ent. Fr., (5) **3,** p. 226.
1938. *Dendrophilus sexstriatus,* Hatch, J. Kans. ent. Soc., **11,** p. 18.

♂: Length, 2·5-3·7 mm.; breadth, 2·0-2·3 mm. Externally very similar to *D. punctatus* (Herbst), from which it may be distinguished as follows: (1) elytra with first stria usually distinct and nearly as long as second but occasionally obsolete or absent except very near base, whereas in *D. punctatus* the first stria is always absent; (2) second stria usually as long and nearly as deeply impressed as third but sometimes feebly impressed and nearly obsolete on middle of disk, whereas in *D. punctatus* the second stria is wanting or only indistinctly represented behind middle of disk by a row of punctures; (3) the intervals of the basal half of the elytra between suture and fifth stria with the punctures abruptly finer and much sparser than those of apical half, the area between the suture and second stria on middle of disk being highly polished and very strongly shining with punctures only about a fourth as coarse as those of apical half and separated usually by five to ten or more diameters, whereas in *D. punctatus* the punctures gradually become finer towards middle of disk and, except for a few very near suture, are about two-thirds as large as apical punctures and are usually separated by two to four diameters; and (4) surface between punctures on middle of disk between first and second intervals without a visible (mag. × 75) microsculpture, whereas in *D. punctatus* there is here a very fine but distinct microreticulation.

♀: Externally similar to male.



FIGS. 49–51. *Dendrophilus xavieri*, Mars., male. (49) Lateral view of genitalia. (50) Dorsal view of tenth abdominal tergite. (51) Ninth abdominal sternite.

Comparative Notes: *D. xavieri* was sunk as a synonym of *D. punctatus* by Ross (1940), who appears to have been guided to some extent by a statement of Wenzel's (*in litt.*) that every gradation could be found between the two in a large series. I have been unable to find any significant gradation in the series of 33 specimens of both species before me. Moreover, as has been pointed out by Ross himself, the distribution of *D. xavieri* supports the view that it is a distinct species. *D. xavieri* occurs on the Pacific Coast of N. America from Canada to California, while *D. punctatus* has not yet been found in this region and is, so far as is known, confined to the Eastern and Central United States. *D. xavieri* has extended its range into the latter region but is there much rarer than *D. punctatus*.

The male genitalia of the two species are nearly identical, and I have been able to find no differences which can be considered to be of specific importance. A few specimens have been dissected of both species, and it appears from these that the anterior sides of the eighth abdominal tergite are not so strongly produced forwards in *D. xavieri* as in *D. punctatus*.

Distribution: Japan, N. America, England.

Habits: Marseul (1873) records it in Japan at the foot of old trees and in the nest of a black ant. Ross (1940) records it in Vancouver in a culture of *Tenebrio*, etc. in bran and in rotting vegetation in San Francisco. During 1942-43, one was found on pumice in a Bristol warehouse, one in rotting grain in the basement of a London flour-mill, and four in a Liverpool flour mill.

Carcinops quattuordecimstriata (Stephens) (figs. 52-53, 55).

1832. *Dendrophilus quattuordecimstriatus*, Stephens, Brit. Ins., **5**, p. 412.
1834. *Paromalus pumilo*, Erichson, in Klug, Jahrb. Insectenk., **1**, p. 169.
1845. *Hister nana*, Leconte, Boston J. nat. Hist., **5**, p. 61, pl. 4, f. 4.

♂: Length, 1·6-2·7 mm.; breadth, 1·1-1·8 mm. Body broadly obovate in outline, rarely nearly subparallel. Cuticle strongly shining and black or (probably only in recently emerged specimens) dark rufo-piceous; black specimens with legs or only tarsi rufo-piceus and antennae with club brownish or reddish testaceous and funicle dark rufo-piceus. *Head* with marginal stria well developed on occiput and on sides and more or less truncate and much less deeply impressed at anterior margin, rarely with transverse anterior section of stria absent or scarcely visible; stria occasionally interrupted at postero-lateral angles. Surface with two sizes of punctures as follows: (1) large round punctures about a third again as coarse as facets of eyes and separated by one to five or more diameters; and (2) punctures about one-half as coarse which are much more regularly distributed, being separated usually by two or three diameters; surface between punctures on middle of front, anteriorly, and on a narrow belt near occipital stria with a very fine transverse to partly reticulate alutaceous microsculpture; surface elsewhere smooth between punctures. *Pronotum* with sides slightly more strongly arcuate anteriorly. Apex with marginal line usually complete but occasionally very indistinct or even absent on middle half; side with marginal line broad, well impressed, and complete from apex to base; base with marginal line very fine and complete but usually completely concealed by base of elytra. Surface with a deep oval or nearly round puncture immediately in front of scutellum, this puncture being about half as large as scutellum; disk with punctures which are very slightly coarser than fine ones of head and are usually separated by three to five diameters; lateral third of pronotum with fine punctures similar to those of disk and also with punctures which are slightly coarser than coarse ones of head and are usually separated by two to five or even more diameters; coarse punctures often absent in a large oval area which is adjacent to lateral margin and half way between base and apex; surface between pronotal punctures smooth. *Elytra* with striae and strial punctures as shown in fig. 52; second to seventh striae extending from near base to near apex; first or sutural stria often absent on basal fourth or fifth and sometimes very feebly impressed elsewhere or only indicated by a row of large punctures; oblique humeral stria fine but long and distinct and posteriorly usually joining seventh stria. Intervals flat and with only fine punctures like middle of pronotal disk; apical non-striate belt of elytra with coarse and fine punctures intermixed as on lateral third of pronotum; coarse and fine punctures sometimes

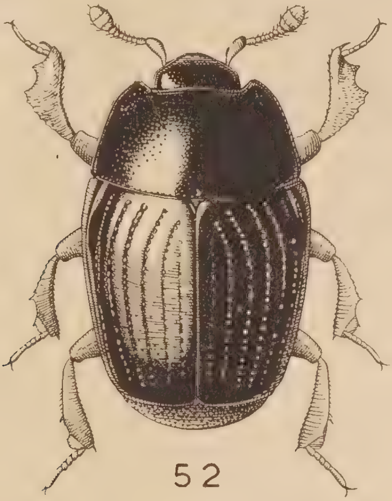

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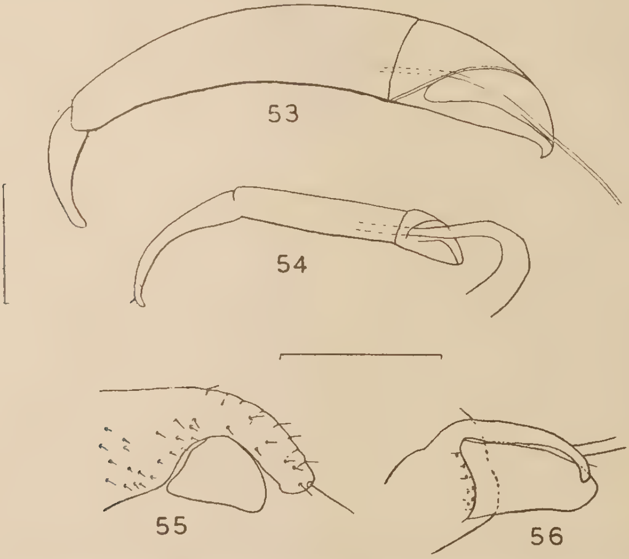
FIG. 52. *Carcinops quattuordecimstriata* (Stephens).

present on apical half of first and second intervals and, more rarely, also on apical half or third and fourth intervals; intervals with surface between punctures smooth. *Propygidium* nearly as long as pygidium and, except for a narrow and finely punctate band as well as apical belt, with both fine and coarse punctures, the coarse punctures usually being slightly but distinctly larger than those of apex of elytra and separated by less than one to two diameters. *Pygidium* finely punctate throughout and basally with numerous, or only a few, coarse punctures which, however, are apparently never as coarse as those of propygidium. *Prosternum* with caudal margin of process broadly rounded and received into a broad arcuate emargination of anterior margin of mesosternum; median striae nearly parallel but slightly more approximate opposite anterior third of front coxa and joined together in a broad curve before apex of process. Mesosternal disk completely and thickly margined laterally and anteriorly; disk with coarse and fine punctures like sides of pronotum. Metasternum with inner lateral striae extending caudally and outwards to basal fifth; outer metasternal stria extending from middle coxal cavity feebly diverges laterally from inner stria and does not extend quite as far posteriorly as the latter; disk punctate like pronotum, *i.e.* with only fine punctures on middle and with both fine and coarse punctures on sides. Abdomen with lateral striae of first sternite nearly parallel but with inner one coarser and extending from near base of anterior process to very near caudal margin, whereas the outer one commences near the inner hind part of the coxal cavity and does not extend quite as near to the caudal margin of the segment.



Figs. 53–56. (53) Lateral view of male genitalia of *Carcinops quattuordecimstriata* (Steph.). (54) Same of *C. mayeti*, Mars. (55) Lateral view of ninth (?) abdominal tergite of *C. quattuordecimstriata*. (56) Same of *C. mayeti*.

♀: Externally similar to male.

Variations: Apart from the variations in punctuation and colour already mentioned, a few specimens have been seen which have only fine punctures on the meso- and metasternal disks and a few which have the coarse punctures confined to the extreme sides of these two sclerites.

Comparative Notes: The differences between this species and *C. mayeti*, Mars., are given under the heading of the latter and in the key.

Distribution: Cosmopolitan. According to Fauvel (1889), it is indigenous to Africa.

Habits: It has been found in rubbish and carrion in Britain (Fowler, 1889); in donkey and human excrement in Germany (Ganglbauer, 1899); in stale "German yeast" under the floor of a London bakehouse (Jennings, 1900); in glue works in Oxford and Queenborough (Fowler & Donisthorpe, 1913); in a bone works at Acton Bridge, Cheshire (Walker, 1916a); in stored cereals in Bordeaux (Dieuzeide & Tempère, 1924); in dead birds on Johnston Is. (Bryan, 1926); under bark in the Samoan Islands (Arrow, 1927); in a coniferous leader damaged by *Pissodes strobi* (Peck) in N. America (Taylor, 1928); in a granary at Reading (Joy, 1932); in rubbish in a glue works on the Isle of Sheppey (Walker, 1932); in the U.S.A. in stored grain, flour, and waste grain in flour mill basements where it is common (Cotton & Good, 1937); in haystack bottom, in cut grass, and in a bird's nest in Windsor Forest (Donisthorpe, 1939); and in wheat in the field and in storage in farms in Kansas (Cotton & Winburn, 1941).

Records of its occurrence during 1942-44 in Britain in structures used to store food are as follows: 1 in broken rice in a railway wagon at Birkenhead, Cheshire; 13 on pumrice in a Bristol warehouse; 2 in an elevator boot; 1 in a Bristol flour mill; numerous adults and larvae in waste grain in the basement of a London flour mill; 6 in a London granary; 4 on palm kernals at Liverpool; and 1 in crushed bones on the Dundee docks.

Parasite: According to Jones (1929), it serves as an intermediate host of *Hymenolepis carioca*.

Carcinops mayeti, Marseul (figs. 54, 56).

1870. *Carcinops mayeti*, Marseul, Ann. Soc. ent. Belg., **13**, p. 94.

♂: Length, 1·4 mm.; breadth, 0·87 mm. Body broadly oval. Cuticle strongly shining and very dark rufo-piceous, nearly black; antennal club testaceous; legs paler rufo-piceous than body, sometimes slightly red-brown. *Head* with clypeus feebly concave and bent downwards so that it is more or less vertical and at an angle of about 60-70° to front. Marginal stria complete basally but absent on sides and front margin of anterior half of front. Surface on basal half with punctures which are slightly finer to slightly coarser than facets of eyes and are usually separated by one to two diameters, the surface between the punctures being scarcely visibly (mag. × 100) alutaceous; surface of concave part of clypeus (and front?) much more finely and sparsely punctate and also distinctly transversely microreticulate and less shining. *Pronotum* with apical and lateral marginal lines distinct and complete. Surface punctate like head but with fine punctures separated by two to five diameters and also with shallow, round to oval punctures which are two or nearly three times as large and are much more irregularly distributed; along base with a single row of punctures which are deeper and half again to twice as coarse as large punctures of disk; surface between punctures smooth or nearly so. *Elytra* with second to seventh stria extending from near base to near apex; first or sutural stria absent on basal third or fourth; apical half with a distinct or indistinct stria between sutural and second striae, this accessory stria sometimes being present only as a row of punctures; oblique humeral accessory stria very fine, indistinct, and posteriorly joining seventh stria; striae distinctly but irregularly crenate with large punctures which may be very widely separated or even absent on basal half of first three striae. Intervals flat and with fine punctures like pronotal disk but on apex with a few round, deep, much coarser punctures; surface between punctures smooth or nearly so. *Propygidium* slightly less than half as long as pygidium and with fine punctures similar to those of head but slightly sparser. *Pygidium* punctate like propygidium but with an occasional distinctly coarser, round puncture. *Prosternum* with caudal apex of process strongly rounded behind (sometimes nearly angulate) and fitting into a deep, arcuate emargination of anterior margin of mesosternum; median striae subparallel, slightly more approximated at middle, feebly curved at extreme anterior end, and joined or nearly joined at caudal apex. Mesosternal disk completely and thickly margined laterally and anteriorly; surface only finely punctate like basal half of head but more finely so. Metasternum with inner lateral stria extending nearly straight backwards to a point near caudal margin of metasternum and mesal to mesal margin of hind coxa; outer metasternal stria broadly sinuate and extending outwards and caudally to a point beyond anterior margin of hind coxa and near episternum; surface punctate like mesosternal disk but middle more finely and sparsely so. Abdomen with a single and complete stria on each side of disk of first sternite; extreme side of this sternite with two narrow nearly complete and approximately parallel striae.

♀: Externally similar to male but with the clypeus feebly convex, on the same plane as the front of the head, similarly punctate, and with the sides and front completely margined.

Comparative Notes: *C. mayeti* differs from *C. quattuordecimstriata* in the following important particulars: (1) it is 1·4 mm. instead of 1·6-2·7 mm. long; (2) the front of the head has no anterior stria and the clypeus is concave; (3) each elytron has a supplementary stria between the sutural and second striae; (4) the propygidium is less than half as long as the pygidium and is only finely punctate instead of being nearly as long as the pygidium and having very coarse and fine punctures intermixed; (5) the inner lateral striae of the metasternal disk are nearly straight instead of oblique; (6) the disk of the first abdominal sternite has only a single lateral stria on each side instead of two; (7) the extreme side of the first sternite has two parallel striae instead of only one; and (8) the male genitalia have the parameres more than half as long as the basal piece instead of only about one-fourth as long (*cf.* figs. 54 & 53).

Distribution: Egypt, Arabia. Introduced into France but not established there.

Habits: It has been found on ground-nuts imported into Marseilles (Marseul, 1870; des Gozis & Fauvel, 1886) and on ground-nuts imported into Cette (Ganglbauer, 1899).

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THE LARVAE OF THE PTINIDAE ASSOCIATED WITH STORED PRODUCTS.

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(Pls. III-IX.)

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Introduction.

In recent years much attention has been given by entomologists and others to the beetles of the family Ptinidae because of the serious losses they cause to stored products, particularly cereals. The adults have been revised by Hinton (1941), but no satisfactory key exists to the larvae. Only those of a few species have been described, and these descriptions are not sufficiently detailed to make it possible to identify the species concerned. By means of the keys and illustrations given here it should be possible to name with certainty the larvae of all the more economically important species.

Altogether, fifteen species of Ptinids have been recorded attacking stored products in the British Isles or have been found in building structures where such products are normally kept. Of these, twelve, *viz.*: *Ptinus tectus*, Boield., *P. hirtellus*, Sturm, *P. latro*, F., *P. fur*, L., *P. pusillus*, Sturm, *P. villiger*, Reitt., *P. raptor*, Sturm, *Niptus hololeucus*, Fald., *Trigonogenius globulus*, Sol., *Gibbium psylloides*, Czemp., *Tipnus unicolor*, Piller & Mitt., and *Stethomezium squamosum*, Hinton, are included in the keys given below. An undetermined species, probably of *Ptinus*, which has been found on two separate occasions and is referred to as *P.* sp. indet., is also included. These twelve species include all those of any importance in this country and, with one or two exceptions, all species of any real importance elsewhere in the world. Three species, *Ptinus exulans*, Er., *Eurostus hilleri*, Reitt., and *Mezium affine*, Boield., which have been recorded in Britain as associated with stored products, are not included in the keys as no specimens were available. Of these three, the first has only rarely been introduced and is not yet established, the second has only recently become established here but appears to feed mainly if not entirely on rat and mouse droppings, and the third is sufficiently rare to be of little or no practical importance.

Bred specimens of all of the species included in the keys have been available with the exception of *Ptinus villiger*, which has been included in the keys on larvae found associated with the adults in a sack of flour. Earlier instar larvae of only a few species have been examined, and the keys are therefore intended only for mature or nearly mature larvae, but it is probable that they will also be useful for identifying first-instar larvae.

In view of the fact that larvae of several other families of the BOSTRYCHOIDEA are sometimes found in warehouses and granaries in the same situations as Ptinid larvae and closely resemble them, the following key appears to be necessary in order to distinguish Ptinid larvae from those of related families.

1. Antenna at least one-third as long as mandible and with three well developed segments or with second and third segments fused together in which case the boundary between the second and third is indicated by a conical sensory appendage. Head partly retracted into prothorax.......................... 2.

— Antenna much less than one-third as long as mandible and consisting of a single minute segment or sometimes two fused segments. Head not retracted into prothorax.. 3

2. Spiracle of eighth abdominal segment several times as large as spiracles of preceding segments .... LYCTIDAE

— Spiracle of eighth abdominal segment not distinctly larger than spiracles of preceding segments ....BOSTRYCHIDAE

3. Thoracic spiracle in membranous area between meso- and prothorax but sometimes appearing to be on caudo-lateral part of prothorax. Dorsal surface of abdomen hairy and with transverse bands of spicules............ANOBIIDAE

— Thoracic spiracle in antero-lateral part of prothorax. Dorsal surface of abdomen hairy but without bands of spicules or stout and short setae or spines .... PTINIDAE

Explanation of Terms used in the Key.

The inter-specific and inter-generic differences are small, and there is much variation in the larvae here considered. Few useful characters can be seen in whole specimens under a lens or binocular, and preparations of the mouth parts and other organs are necessary for their microscopic examination. A magnification of about 500 should be used. Colour, shape, and size are not of taxonomic value. The characters used in the key are described below, together with their intra-specific variations. Variation in the numbers and disposition of setae on different individuals of a species, and on the two sides of the body of one individual is considerable. The main variations of this type which have been found in the characters used in the key are enumerated.

The single jointed minute antenna (Pl. III, figs. 22-31) shows little marked intra-specific variation. The length of the tactile appendix (terminology used by Böving, 1927) is fairly constant and varies in different species, and reference to the shape of the appendix is made by a statement of the ratio of the length to the width. The greatest intra-specific variation occurs in *Ptinus fur* where the length may be two to almost three times the width.

The labral sensillae are usually constant in number. They can be seen through the epipharynx, and are shown by dotted circles on Pls. IV & V. Only three specimens have been seen with sensillae more or less numerous than other specimens of the same species, these are one of *P. fur* with two instead of three sensillae, the median sensilla being absent, and two of *P. latro*, one lacking a median and a lateral sensilla, and the other lacking a lateral sensilla, the remaining sensillae being in their normal positions. There is considerable bilateral and individual variation in the exact positions of the sensillae, which are only roughly symmetrical.

A pair of Y-shaped sclerites (Pls. IV & V) are present in the labrum, visible from either the labral or epipharyngeal sides. They are variable in shape and in extent, but some of their features are sufficiently constant to be of taxonomic value.

The two arms of the Y may be about equal in width, in length, and in colour, or one may be markedly wider than the other or may be shortened to form a small knob. Bilateral variations are usually not as great as those shown for *Stethomezium squamosum* (Pl. V, fig. 41). In the eight species where the sclerite is roughly similar, the inner arm is usually as wide or almost as wide as the outer arm, but occasionally it is decidedly narrower.

The form and arrangement of setae on the epipharynx (Pls. IV & V) show a similar basal plan in all species examined. The setae can be grouped into sets (see below). In order to facilitate reference to particular setae or sets of setae in the key, a plan showing the positions of the setae is given in the diagram (fig. 1). The numbers and the positions of setae in all sets are subject to considerable variation, and the setae on the two sides are seldom mirror images of each other, yet in spite of this the chaetotaxy of the epipharynx is of taxonomic value. In all figures of the epipharynx the bases of setae inserted on the epipharynx are shown.

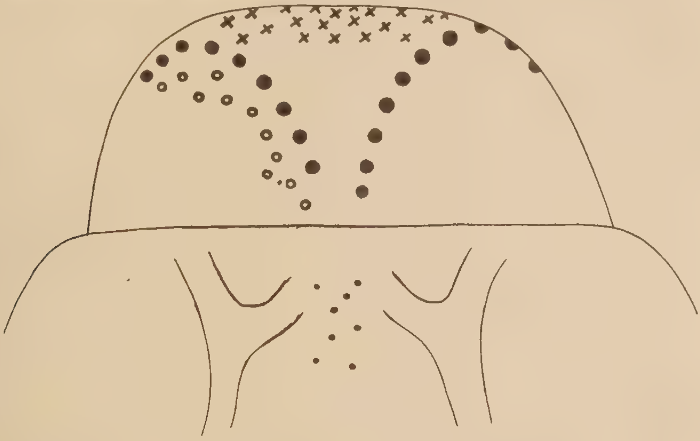

FIG. 1. Plan showing the distribution of sets of setae on the epipharynx; for explanation see text.

The bases of the labral setae are not shown, but the parts of these setae projecting beyond the margin of the epipharynx are figured, as they give an indication of the degree of hairiness of the species.

The main pair of diverging rows of setae are marked by large dots. In some species these comprise a pair of irregular diverging rows of large, often flat, setae lying across the epipharynx. In other species these rows merge more or less evenly into an additional arc of large setae situated near (left side of diagram) or on (right side of diagram) the margin of the epipharynx. The larger and more conspicuous setae of the diverging rows can usually be recognised on each side in all specimens, but the proximal extent of these rows varies, as does their extension on to the lateral margin, where they may either form a continuation of the diverging rows, or an irregular row or group (*e.g.* in *P. fur* the diverging rows usually consist of 4 setae, but sometimes 3 or 5, lying across the epipharynx, and from 1-3 setae on or near the lateral margin; and in *P. pusillus* the diverging rows usually consist of 5 setae, but sometimes 4 or 6, lying across the epipharynx, and from 2-4 setae on or near the lateral margin, in the series of specimens examined).

The irregular transverse rows near the front margin are marked by crosses, and lie between the diverging rows. The numbers of setae here present are not given, although significant, because of the difficulty of determining the point at which these setae merge into those of the labrum which are inserted on the other side.

Setae lateral to the diverging rows are marked by circles. This set may be absent (right side of diagram); it may form on each side a fairly regular row or rows lateral and parallel to the diverging rows; or more numerous setae less orderly in arrangement may lie between the diverging rows and the lateral margins of the epipharynx. This set shows greater bilateral and individual variation than do the diverging rows, and the variations are most conspicuous in species where the setae of this series are few (*e.g.* in *P. pusillus* there may be no setae lateral to the diverging rows on either side, or from 1-6 setae may be present, and the bilateral asymmetry may be as much as 6 setae on one side and 2 on the other; and in *P. fur* one seta of this series is developed occasionally on one or other side in the series of specimens examined).

A basal median group of small setae are marked by small dots. They lie between the inner arms of the Y-shaped sclerites. They may or may not be present, and if present, may or may not merge with the main pair of diverging rows of setae. They show no constancy in exact position or in numbers, and there is little trace of bilateral symmetry. The most conspicuous intra-specific variations noted in the series examined are 1-2 setae in *P. fur* and 3-8 in *P. pusillus*.

The mandible (Pl. III, figs. 1-13) shows little intra-specific or bilateral variation. In some species the tooth on the mesal margin is small, acute, and abruptly projecting, and is situated a little nearer to the apex than to the base; the size of this tooth varies in different species. The general shape of this type of mandible is as shown in Pl. III, figs. 1-7. Alternatively, the tooth on the mesal margin may be obtuse, and it is then situated either midway along this margin or nearer to the apex or to the base, and the shape of the mandible is various (Pl. III, figs. 8-13).

Only the setae situated on the upper surface of the labium (Pl. VI) are used in the key, and in the figures only these are shown. The setae inserted on the lower surface are not figured although visible in the preparations. The limits between the segments of the labium are not visible on the thin-walled upper surface, although conspicuous on the lower surface. A horizontal fold lies across the labium near the junction of the prementum and postmentum, where the distal part of the labium telescopes into the proximal part; the visible degree of telescoping differs slightly in different preparations, and this may affect the apparent position of setae. The following sets of setae are referred to in the key.

A conspicuous pair of strong setae lies near the middle line in all species. These setae may be inserted in or very close to the fold in some species, or some distance proximal or distal to it in others. They appear to be homologous, but it has not been ascertained whether they belong to the prementum or postmentum. In some species these setae are not stronger than others on the prementum (Pl. VI, figs. 54-56), while in other species they are markedly stronger, at least twice as wide as other setae on the prementum (Pl. VI, figs. 45-53). In some species there is a variable number of additional setae irregularly disposed near the main pair (Pl. VI, figs. 48 & 52). The following intra-specific variations have been noted. In the species where the pair of dorsal setae are inserted near the fold across the labium, *e.g.*, *P. fur* and *P. pusillus*, the position of the fold in different preparations may leave the dorsal setae either just anterior or just posterior to the fold, but it is not unlikely that the positions of the setae vary as well as the position of the fold. The setae are not always symmetrically placed, although they are usually of the same size. When additional setae are present, they show very little bilateral symmetry and much individual variation in numbers.

All species show one or more setae forming an irregular lateral row across the base of the prementum. This row may continue laterally to the lower side of the labium, but only those setae inserted on its upper surface are referred to in the key. Their number varies in different species, and small individual and bilateral variations occur.

Distal to the above setae, the larger species may show a few setae which, when sufficiently numerous, form laterally a transverse row at the base of the palp. When only one or two setae are present, they appear to be inserted on the prementum (Pl. VI, figs. 47, 50 & 54), but when three or four occur, as in *Niptus hololeucus* (Pl. VI, fig. 56), the row extends across the basal segment of the palp to its lateral border. The most conspicuous intra-specific variations occur in *P. pusillus* with 0-1 setae, in *P. fur* with 0-2 setae, and in *N. hololeucus* with 3-4 setae in this position.

Paired setae project beyond the anterior margin of the prementum between the palps. They are situated on or near the anterior margin, but their exact positions are variable. Only those setae inserted in the anterior margin of the prementum or on its upper surface are referred to in the key and are shown in the figures; setae which may be inserted here on the lower surface are not considered. When one or two pairs of setae are present they are clearly inserted on the prementum (Pl. VI, figs. 47 & 56), but when more numerous, they spread laterally on to the basal segment of the palp (Pl. VI, fig. 48). Short setules may be present or absent on the upper surfaces of the lateral parts of the prementum and the basal segment of the palp.

The legs (Pls. VII & VIII) show minor intra-specific variations in the shape of the claw, the empodial lobe when present, and in the number and exact positions of the setae, but the form of the claw and the general disposition of setae is common to all three pairs of legs and definite for each species.

The base of the claw bears one large seta situated on the mesal or antero-mesal border in all species. In *Trigonogenius globulus* an additional 1-3 setae are present on the posterior face (Pl. VIII, fig. 62), they are usually nearly as long as the claw, but they may project little beyond the empodial lobe. In all species except *N. hololeucus* an empodial lobe is present on the posterior side of the claw on all legs. In *T. globulus* and *Tipnus unicolor* the lobe is smaller than in other species and variable in extent. The entire margin is sometimes clearly defined, but in some specimens (Pl. VIII, figs. 62 & 65) the edge of the lobe does not appear to extend right across the claw. In the remaining 10 species showing a well defined empodial lobe, the variations in the shape of the latter are sufficient to render the exact shape of the lobe of little taxonomic value (*e.g.*, *P. fur* may appear as in Pl. VII, fig. 57, or the mesal margin of the lobe may be as shown in Pl. VII, fig. 59 for *P. villiger*).

The setae on the tibia show several distinct patterns of distribution. Two setae are situated distally on the upper surface near the claw in all species except *Stethomezium squamosum*, which bears only one seta in this position (Pl. VIII, fig. 63). A group of setae, usually 2-3 in number (Pl. VII, figs. 57 & 59 and Pl. VIII, fig. 61), but more in some species (Pl. VII, figs. 58 & 60), lie on the ventral side about half way along. On the dorsal surface the setae may be absent from the proximal half (Pl. VII, fig. 59) or quarter (Pl. VIII, figs. 57, 58 & 60) or may spread all along (Pl. VIII, figs. 61-64); when absent from the proximal quarter there is either a marked gap between the two dorsal setae near the claw and the rest, which form a band round the middle of the joint (Pl. VII, fig. 57 and Pl. VIII, fig. 65), or the setae spread all along to the two distal dorsal setae (Pl. VII, fig. 60). When setae are present dorsally on the proximal quarter their total number may be few, 5-6 in *S. squamosum* (Pl. VIII, fig. 63), or many, 10-21 (Pl. VIII, figs. 61 & 62). The number and exact positions of the setae on the tibia are very variable, but even in *Trigonogenius globulus*, where the widest range in numbers of setae has been found (11-23), the general disposition of the setae is constant and equally clear whether the numbers are small or large.

The spiracles (Pl. III, figs. 14-21) may be large, medium sized, or small, the length of the mandible being about 1½, 2-3½, or 5½-6½ × the diameter of the spiracle respectively. The peritreme usually forms a lip projecting upwards and backwards. The eight pairs of abdominal spiracles are similar in general form, except that the lip on the 7th pair may be the longest and that on the 8th pair is usually shorter than the rest and may be almost absent. The prothoracic spiracles are larger than those on the abdomen and often slightly different in shape. In *Niptus hololeucus* the lip is short and present on some segments only (Pl. III, figs. 14A & B). In *T. globulus* the lip is not much narrower than the spiracle, and the sides of the lip tend to converge (Pl. III, figs. 18A & B). In all other species the lip is long and its sides approximately parallel (Pl. III, figs. 16, 17, 19-21).

Variations in the size of the spiracles and in the form of the lip of the peritreme are so great among specimens of *P. fur* and *P. latro*, that the considerable differences which are apparent between the nine species with medium sized spiracles may not be of reliable taxonomic value; they have not been referred to in the key and are summarised on p. 345. The length of the lip is more variable than its width. In species where the lip is long there is considerable bilateral symmetry between spiracles of a pair, but where the lip is short, as in *Niptus hololeucus* and *P. villiger*, there may be much bilateral variation (*e.g.* in *P. villiger* a lip may be present on one side only of the prothorax, although occurring on both sides of all abdominal segments; and in *N. hololeucus* a small lip, bilaterally unequal in size, may occur on the prothorax, and a small lip may be present on some of the abdominal spiracles, but showing no bilateral symmetry in its presence or in its size, and appearing on different segments in different individuals). In *Trigonogenius globulus* where the lip is relatively wide, the sides of the lip tend to be parallel when the lip is long, but on most segments the sides converge. Parallel sided lips may occasionally be found on different segments in different individuals.

The preanal sclerite and the setae near it show such extensive intra-specific variation that only gross differences can be used in the key. In species where the sclerite is large and U-shaped, the arms may be equal or unequal, and may embrace a variable length of the anal groove (*e.g.*, less than one-third to a half in *P. pusillus* and either more or less than a half in *P. fur*). The inner margin of the sclerite may be either U- or V-shaped and the width of the sclerite is variable in different individuals. In species with a small sclerite, where the arms are short and diverge widely so that they embrace only the extreme end of the anal groove, the sclerite is frequently asymmetrical and the outline various (*e.g.*, *T. globulus* (Pl. IX, figs. 67 & 68), where the arms may be so short as to form a triangular sclerite). The setae near the anus and anal sclerite are arranged in sets, and their abundance appears to be correlated with the degree of hairiness of the body, but there is so much bilateral and individual variation that no satisfactory taxonomic employment of these features has been found.

The degree of hairiness of the body is probably of taxonomic value, but no simple method of evaluating this feature has been devised. The length and abundance of the labral setae are probably correlated with the degree of hairiness of the body and legs; the labral setae projecting beyond the margin of the epipharynx are shown in the figures and record the density and length for each species.

Inter-Generic and Inter-Specific Differences.

The chaetotaxy of the species here considered is correlated to a certain extent with the absolute size of the animals. The smaller species, such as *Tipnus unicolor* and *Stethomezium squamosum*, have fewer and relatively larger setae than the larger ones, such as *P. fur*, *P. pusillus*, *Trigonogenius globulus* and *Niptus hololeucus*. Different species of closely similar size also show differences in abundance and size of setae. *P. villiger*, for example, has fewer, shorter setae than *T. globulus*, *P. pusillus* and *P.* sp. indet., but these differences are not so striking as those between the larger and smaller species.

Many of the inter-generic and inter-specific differences shown by the species here considered have been referred to in the key, and the remainder are noted here. All these characters are illustrated by the figures. In considering the inter-specific differences, the extensive intra-specific variations must be borne in mind.

The length of the tactile appendix of the antenna is about equal to the breadth in *Gibbium psylloides* and in *Niptus hololeucus*; it is about 1½ × the breadth in *Trigonogenius globulus, Stethomezium squamosum, P.* sp. indet. and *P. tectus;* about 2-2½ × the breadth in *Tipnus unicolor, P. pusillus, P. hirtellus, P. latro, P. raptor,* and *P. fur*; and about 3 × the breadth in *P. villiger.*

There are three labral sensillae in all species except *P. hirtellus* and *Niptus hololeucus,* where there are four.

The inner arm of the Y-shaped sclerite in the epipharynx is very much shorter than the outer arm in *Trigonogenius globulus,* and in *P. villiger* it is extremely short and knob-like. In all others the inner arm is almost or quite as long as the outer arm, and, except in *P. tectus, P.* sp. indet. and *Gibbium psylloides* where the inner arm is distinctly wider than the outer arm, the inner arm is either narrower or the same width as the outer arm. In *P. tectus* and *P.* sp. indet. the wide inner arms tend to unite with one another across the middle line (Pl. V, figs. 38 & 42).

Setae on the epipharynx have not been fully described in the key. Their characters in each species can be ascertained by reference to the figures and to the intra-specific variations noted on p. 343. They show fairly easily distinguishable patterns in the genera of which only one species has been seen, although *Trigonogenius globulus* may appear not unlike *P.* sp. indet. Within the genius *Ptinus, P. fur, P. raptor, P. hirtellus* and *P. latro* show almost indistinguishable patterns and *P. villiger* is very close to them, while *P. tectus* differs from the other species as greatly as any of them differ from the other genera.

The mandibles of seven of the eight species of *Ptinus* are very alike. The acutely projecting tooth on the mesal margin is smallest in *P. raptor* and *P. villiger,* largest in *P. latro* and *P.* sp. indet., and intermediate in *P. hirtellus, P. fur,* and *P. pusillus.* The mandibles of *P. tectus* and the other genera have an obtuse tooth on the mesal margin, which is situated nearer to the base in *Tipnus unicolor* and nearer to the apex in *P. tectus, Niptus hololeucus, Trigonogenius globulus, Gibbium psylloides* and *Stethomezium squamosum.*

Setae on the upper side of the labium are not always easy to observe, and the differences between some species are not great. Six species of *Ptinus* differ only slightly: *P. fur* and *P. hirtellus* are alike with 4-5 setae on each side across the base of the prementum, 0-2 setae at the base of the palps, 2 pairs of setae projecting beyond the anterior margin of the prementum between the palps, and a few setules on the basal joint of the palp but none on the prementum. *P. pusillus* and *P. villiger* resemble each other and differ from the above in having 6-7 setae on each side across the base of the prementum, 0-2 setae at the base of the palps, 1-2 pairs of setae projecting beyond the anterior margin of the prementum between the palps, and many setules situated both on the basal joint of the palp and on the lateral parts of the prementum. *P. raptor* and *P. latro* have fewer setules than *P. pusillus* and *P. villiger,* and are intermediate between the above two pairs of species, and are not clearly distinguishable from either. The remaining species are each quite distinct. *Niptus hololeucus* and *Trigonogenius globulus,* like *Stethomezium squamosum,* have the pair of setae near the middle line not markedly stronger than other setae on the prementum and differ in that *N. hololeucus* has 3-4 setae on each side at the base of the palp and setules on the basal segment of the palp only, while *T. globulus* has one seta on each side at the base of the palp and setules on the prementum and on the basal segment of the palp. The other five species are described in the key.

The tarsus is similar in all eight species of *Ptinus* and in *Stethomezium squamosum, Gibbium psylloides* and *Tipnus unicolor,* although the empodial lobe is ill-defined in *T. unicolor. Trigonogenius globulus* and *Niptus hololeucus* each show a distinct type.

The setae on the tibia are indistinguishable in number and arrangement in *P. fur, P. tectus, Tipnus unicolor* and *Gibbium psylloides* with 8-13 setae which are absent from the proximal quarter and arranged as in Pl. VII, figs. 57, 58, & Pl. VIII, fig. 65. *P.* sp. indet. is very like these but has more setae (15-21) (Pl. VII, fig. 60). *P. raptor* differs from the above five species in the setae on the dorsal side extending along the whole of the distal two-thirds of the tibia. *P. villiger* and *Stethomezium squamosum* are each distinct from all others as noted in the key. *P. latro, P. hirtellus,* and *Niptus hololeucus* are indistinguishable from each other with setae present on the proximal quarter, and numbering 10-15. *P. pusillus* differs only in having more setae (19-20), and *Trigonogenius globulus* may resemble any of these four species, bearing 11-23 setae.

The preanal sclerite is large and U-shaped in *P. fur, P. pusillus, P. hirtellus, P. latro, P. raptor,* and *P. villiger,* and small in *P.* sp. indet, and *P. tectus* and the other genera.

The five genera represented by one species each can be readily identified by the following characters: *Niptus hololeucus* by the tarsus, spiracles, epipharynx and labium; *Trigonogenius globulus* by the tarsus, spiracles and labium; *Tipnus unicolor* by the mandible, epipharynx and labium; *Stethomezium squamosum* by the spiracles, epipharynx and labium; and *Gibbium psylloides* by the epipharynx and labium. The genus *Ptinus,* represented by eight species, cannot be diagnosed by any character common to all the species in contrast to the other genera. *P. tectus* may be readily distinguished from the other species by its very distinct mandible and epipharynx and the presence of a small preanal sclerite, and *P. villiger* by its very distinct type of spiracle, Y-shaped sclerite in the labrum, and setae on the tibia. *P. fur, P. raptor, P. pusillus, P. hirtellus* and *P. latro* are closely similar in most features. *P. hirtellus* is easily separable by its four labral sensillae, but is otherwise indistinguishable from *P. latro,* and the others are separable as shown in the key. *P.* sp. indet. resembles *P. tectus* and differs from the other species of *Ptinus* in many characters, *viz.,* the small preanal sclerite, the length of the antenna, the shape of the Y-shaped sclerite in the labrum, the presence of additional setae near the strong pair near the middle line on the upper side of the labium, and in having more than two pairs of setae projecting beyond the anterior margin of the prementum, but the two species are very unlike in the mandible, the epipharynx, the labral setae, and in size.

In the adult beetles, Hinton (1941) has noted that *P. tectus* may be readily distinguished from other species of the genus, that *P. fur* and *P. pusillus* are closely related, and that *P. hirtellus* is very close to *P. latro.* Thus as far as larval material has been examined, the species which appear to be closely or distantly related in the adult state show the same relationships in the late larval phase.

Characters common to the Ptinid Larvae referred to in the Key.

Böving (1927) has commented on the classification of families connected with the ANOBIIDAE and on the relationship of the PTINIDAE to the ANOBIIDAE, and he characterises the larvae of the tribes and genera of the latter. The characters common to the Ptinid larvae considered in this key are given below so that a ready comparison may be made between them and the larvae of related groups.

Labrum hairy. Epipharynx with a pair of diverging rows of spine-like setae about 5-10 in number, with irregular transverse rows near the front margin between the diverging rows comprising 5 or more setae, and sometimes with additional setae lateral to the diverging rows. No median or paramedian chitinous marks. A pair of Y-shaped sclerites present in the labrum, visible from either labral or epipharyngeal sides. Mandible with one apical tooth and one tooth about half way along the mesal margin. Maxillary mala simple, but with inner and outer parts differentiated; the inner part bears one large chitinous process, 2 large spines and other setae, and the outer part bears many stout spines and other setae. Labium with prementum forming no projection distally between the palps. One pair of strong setae present near the middle line on the upper side near the junction of the prementum and and mentum. Tibia with long hairs more or less evenly distributed, no short spines. Body covered with long soft hairs. Preanal sclerite present.

KEY TO MATURE OR NEARLY MATURE LARVAE OF THE PTINIDAE.

1. Preanal sclerite large, U-shaped, reaching to about the middle of the anal groove (Pl. IX, fig. 66) 2

— Preanal sclerite small, variable in size and shape, the arms of the triangular or slightly U-shaped sclerite too short to embrace more than the extreme end of the anal groove (Pl. IX, figs. 67 & 68)....................................7

2. Labrum with 4 sub-basal sensillae (Pl. IV, fig. 32).........*Ptinus hirtellus*, Sturm

— Labrum with 3 sub-basal sensillae (Pls. IV & V).......................................3

3. Width of the first abdominal spiracle (Pl. III, fig. 15) is about 6 × that of its lip; spiracles large, length of mandible being about 1·5 × the longest diameter of the first abdominal spiracle. The inner arm of the Y-shaped sclerite in the labrum very much shorter than the outer arm, knob-shaped (Pl. IV, fig. 33). Tibia with setae absent from the proximal half of the upper surface, and bearing about 7-8 setae (Pl. VII, fig. 59). ....*Ptinus villiger*, Reitt.

— Width of the first abdominal spiracle (Pl. III, figs. 16, 17 & 20) is about 2-3½ × that of its lip; spiracles medium sized, length of mandible being 2-3½ × the longest diameter of the first abdominal spiracle. The inner arm of the Y-shaped sclerite in the labrum (Pl. IV, figs. 34-37) as long or almost as long as the outer arm. Tibia with setae present on the proximal half of the upper surface (Pl. VII, figs. 57 & 60; Pl. VIII, fig. 61) 4

4. Tibia with setae absent from the proximal quarter of the upper surface (Pl. VII, figs. 57 & 60) 5

— Tibia with setae present on the proximal quarter of the upper surface (Pl. VIII, fig. 61) 6

5. Tibia with setae extending dorsally along the whole of the distal two-thirds or three-quarters, total number about 21-23 (Pl. VII, fig. 60). Tooth on the mesal margin of the mandible (Pl. III, fig. 6) slightly smaller and projecting markedly less than in *P. fur*..................*Ptinus raptor*, Sturm

— Tibia with setae forming a band round the middle which is separated by a gap from two dorsal setae near the distal end, total number 8-13 (Pl. VII, fig. 57). Tooth on the mesal margin of the mandible (Pl. III, fig. 3) slightly larger than in *P. raptor* and projecting acutely..................*Ptinus fur*, L.

6. Tibia with about 19-20 setae. The epipharynx (Pl. IV, fig. 35) with the main pair of diverging rows of setae numbering about 7-9 and sharper than in *P. latro*; with the setae lateral to the diverging rows numbering 0-6 and tending to form one subsidiary row parallel to the diverging rows; with a basal median group of 3-8 small setae; and with the setae composing the irregular transverse rows near the front margin, between the diverging rows, tapering and sharp and more numerous than in *P. latro*. ....*Ptinus pusillus*, Sturm

— Tibia with about 12-13 setae. The epipharynx (Pl. IV, fig. 36) with the main pair of diverging rows or setae numbering about 7 and blunter than in *P. pusillus*; with setae lateral to the diverging rows usually absent; with the basal median group usually represented by one seta; and with the setae composing the irregular transverse rows near the front margin, between the diverging rows, blunter and fewer than in *P. pusillus*. ....*Ptinus latro*, F.

7. Claw of tarsus (Pl. VIII, fig. 64) without empodial lobe. Labrum with 4 sub-basal sensillae (Pl. V, fig. 44). Epipharynx with the main pair of diverging rows of setae each bearing a large flat pointed seta situated proximal to a large flat seta with a very blunt extremity. Spiracles (Pl. III, figs. 14 A & B) with a short lip on the peritreme on some segments and no lip on others; width of the first abdominal spiracle is about $4\frac{1}{2}$ × that of its lip when the lip is present; spiracles medium sized. Upper side of labium (Pl. VI, fig. 56) with a transverse row of 3-5 setae at the base of the palp ....*Niptus hololeucus*, Fald.

— Claw of tarsus with an empodial lobe (Pl. VII, figs. 58-60; Pl. VIII, figs. 61-63 & 65). Labrum with 3 sub-basal sensillae (Pl. IV, figs. 33-37; Pl. V, figs. 38-43). Epipharynx not as above. Spiracles with a long lip on the peritreme on most segments other than the eighth abdominal segment (as in Pl. III, figs. 16-21); the width of the first abdominal spiracle is $1\frac{1}{2}$ × that of its lip, when the lip has parallel sides............................8

8. Claw of tarsus (Pl. VIII, fig. 62) bearing a few (1-3) setae on the posterior side in addition to the seta on the antero-mesal border. The lip on the peritreme of the spiracles (Pl. III, figs. 18 A & B) on most segments is wider towards the base, and the sides tend to converge instead of being parallel on many segments. The inner arm of the Y-shaped sclerites in the labrum (Pl. V, fig. 43) is considerably shorter than the outer arm. ....*Trigonogenius globulus*, Sol.

— Claw of tarsus (Pl. VII, figs. 57-60; Pl. VIII, figs. 61 & 63-65) bearing no setae on the posterior side in addition to the seta on the mesal or antero-mesal border. The lip on the peritreme of the spiracles (as in Pl. III, figs. 16, 17 & 19-21) has approximately parallel sides and is not markedly wider near its base. The arms of the Y-shaped sclerites in the labrum (Pl. V, figs. 38-42) are approximately equal in length 9

9. Distal margin of the epipharynx (Pl. V, fig. 39) distinctly concave in the middle line. The upper surface of the labium (Pl. VI, fig. 53) with one pair of strong setae near the middle line, at least twice as wide as other setae on the prementum, and about 1-2 additional setae; with about 3 setae on each side across the base of the prementum; and with a few setules on the basal segment of the palp and prementum. .... *Gibbium psylloides*, Czemp.

— Distal margin of the epipharynx (Pl. V. figs. 38 & 40-42) convex or straight in the middle line. Labium not as above......................................10

10. Epipharynx (Pl. V, figs. 40 & 41) small, less than 130 μ wide at the transverse fold; with the setae of the diverging rows numbering about 5; and with setae lateral to the diverging rows absent. The upper side of the labium (Pl. VI, figs. 51 & 55) bearing no strong setae near and in addition to the pair near the middle line..11

— Epipharynx (Pl. V, figs. 38 & 42) larger, more than 160 μ wide; with the setae of the diverging rows numbering more than 5; and with setae lateral to the diverging rows present. The upper side of the labium (Pl. VI, figs. 48 & 52) bearing several strong setae near and in addition to the pair near the middle line 12

11. Claw of tarsus (Pl. VIII, fig. 65) with a small empodial lobe which may be ill-defined; the base of the brown part of the claw not markedly expanded on the mesal side. Setae on the tibia absent from the proximal quarter of the dorsal surface, and about 9-10 in number. The two proximal pairs of setae on the diverging rows on the epipharynx (Pl. V, fig. 40) are almost the same distance apart. Mandible (Pl. III, fig. 11) wide, the

length being about 1·2 × the width; the tooth on the mesal margin obtuse, its point being nearer to the base than to the apex of the mandible. Tactile appendix of antenna (Pl. III, fig. 28) almost twice as long as wide. The upper side of the labium (Pl. VI, fig. 51) bearing one pair of strong setae near the middle line, at least twice as wide as other setae on the prementum; and with a few setules on the prementum and basal segment of the palp. Spiracles medium sized, the length of the mandible being about 3 × the diameter of the first abdominal spiracle ....*Tipnus unicolor,* Piller & Mitt.

— Claw of tarsus (Pl. VIII, fig. 63) with a large clearly defined empodial lobe; the base of the brown part of the claw markedly expanded on the mesal side distal to the seta. Tibia with setae present on the proximal quarter of the dorsal surface and numbering about 5-6. The basal pair of setae of the diverging rows on the epipharynx (Pl. V, fig. 41) separated by a distance of half that which separates the next pair of setae. Mandible (Pl. III, fig. 9) narrower than in *Tipnus unicolor,* length being about 1½ × the width; tooth on the mesal margin obtuse, its point being nearer to the apex than to the base of the mandible; the apex of the mandible more curved than in *T. unicolor.* Tactile appendix of the antenna slightly longer than wide (Pl. III, fig. 30). The upper side of the labium (Pl. VI, fig. 55) bearing one pair of setae near the middle line which are not stronger than other setae on the prementum; no setules present on the prementum or on the basal segment of the palp. Spiracles (Pl. III, fig. 19) small, the length of the mandible being about 6½ × the diameter of the first abdominal spiracle..............*Stethomezium squamosum,* Hinton

12. Few setae on the epipharynx (Pl. V, fig. 38); the setae on the diverging rows are all distal to the Y-shaped sclerites; no median group of setae present between the inner arms of the Y-shaped sclerites; and there are a few setae lateral to the diverging rows. Mandible (Pl. III, fig. 8) wide, the length being about 1·2 × the width; the tooth on the mesal margin obtuse. The upper side of the labium (Pl. VI, fig. 48) with 1-2 setae on each side across the base of the prementum; with about 4 pairs of setae projecting beyond the anterior margin of the prementum between the palps. Tibia with about 11 setae. Fewer setae on the labrum and round the anus than in *Ptinus* sp. indet. ....*Ptinus tectus,* Boield.

— Many setae on the epipharynx (Pl. V, fig. 42); the diverging rows of setae are not separable from a median basal group of small setae between the inner arms of the Y-shaped sclerites; many setae lateral to the diverging rows are present. Mandible (Pl. III, fig. 1) narrower than in *P. tectus,* the length being about 1·4 × the width; the tooth on the mesal margin acute. The upper side of the labium (Pl. VI, fig. 52) with about 3-5 setae on each side across the base of the prementum; and with about 5-7 pairs of setae projecting beyond the anterior margin of the prementum between the palps. Tibia (Pl. VII, fig. 58) with about 15-21 setae. Many setae on the labrum and round the anus ....*Ptinus* sp. indet.

Acknowledgment.

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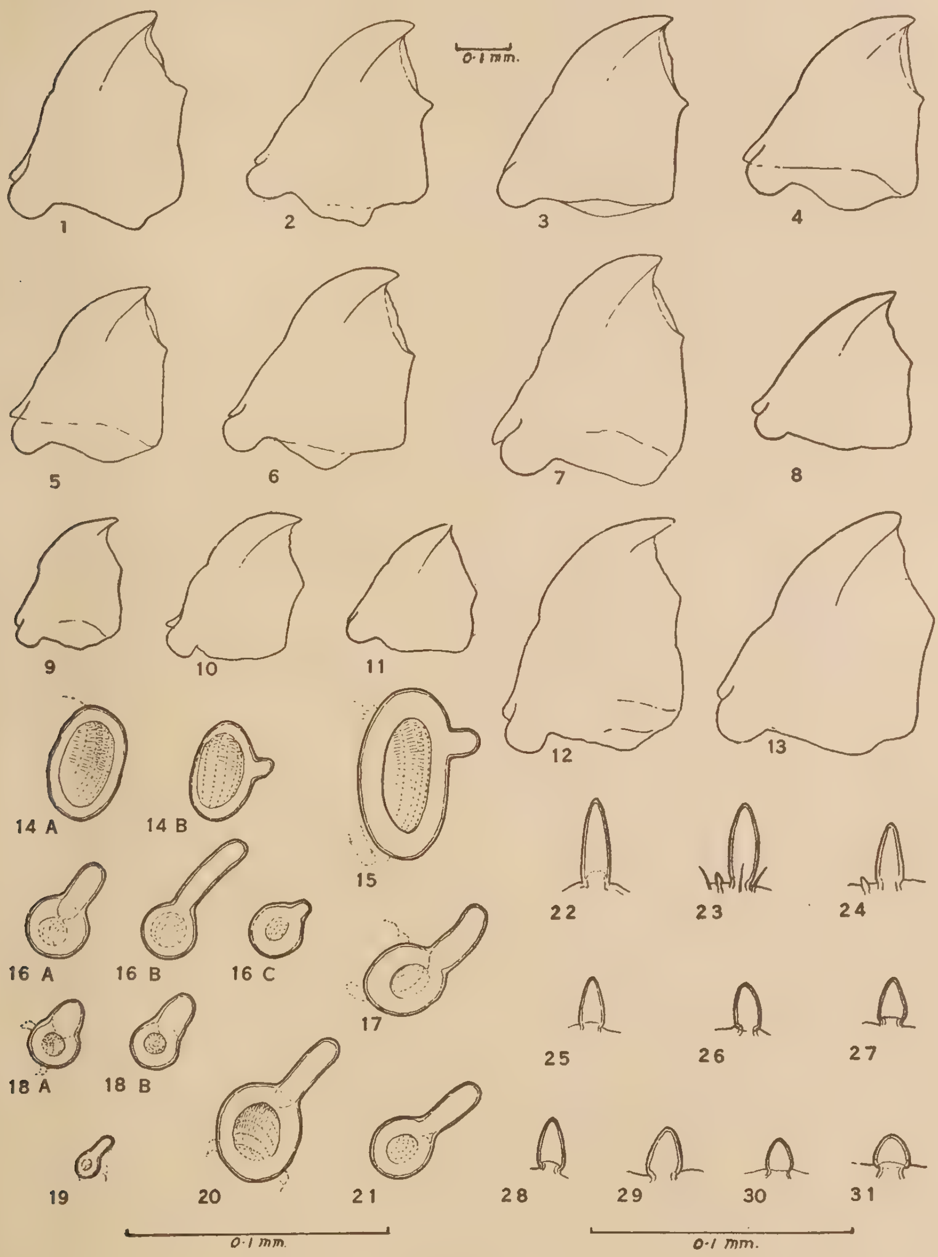
EXPLANATION OF PLATE III.

FIGS. 1–13.—Mandibles: (1) *Ptinus* sp. indet. (2) *P. latro*. (3) *P. fur*. (4) *P. pusillus*. (5) *P. hirtellus*. (6) *P. raptor*. (7) *P. villiger*. (8) *P. tectus*. (9) *Stethomezium squamosum*. (10) *Gibbium psylloides*. (11) *Tipnus unicolor*. (12) *Niptus hololeucus*. (13) *Trigonogenius globulus*.

FIGS. 14–21.—Peritreme of Spiracles: (14 A, B) First and third abdominal spiracles of *Niptus hololeucus*. (15) First abdominal spiracle of *Ptinus villiger*. (16 A–C) First, seventh and eighth abdominal spiracles of *P. latro*. (17) First abdominal spiracle of *P. fur*. (18 A, B) First and third abdominal spiracles of *Trigonogenius globulus*. (19) First abdominal spiracle of *Stethomezium squamosum*. (20) First abdominal spiracle of *P. pusillus*. (21) First abdominal spiracle of *P. hirtellus*.

FIGS. 22–31.—Tactile Appendix of Antenna: (22) *P. villiger*. (23) *P. fur* (*P. raptor* may be like this or like fig. 25). (24) *P. pusillus*. (25) *P. hirtellus* (*P. latro* is very like this). (26) *P.* sp. indet. (27) *P. tectus*. (28) *Tipnus unicolor*. (29) *Trigonogenius globulus*. (30) *Stethomezium squamosum* (*Gibbium psylloides* is very like this). (31) *Niptus hololeucus*.

Bull. Ent. Research. Vol. 35. Plate III.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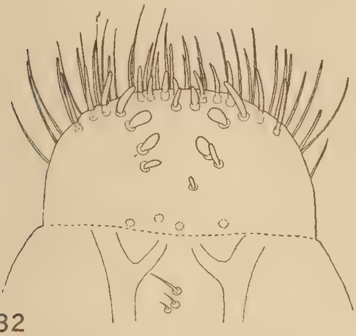
EXPLANATION OF PLATE IV.

Figs. 32–37.—Epipharynx, with labral sensillae seen through the epipharynx shown by dotted circles. The bases of the labral setae are not shown, but the parts of these setae projecting beyond the margin of the epipharynx are drawn. (32) *Ptinus hirtellus.* (33) *P. villiger.* (34) *P. raptor.* (35) *P. pusillus.* (36) *P. latro* (the absence of one lateral sensilla in this specimen is probably abnormal). (37) *P. fur.*

Bull. Ent. Research. Vol. 35. Plate IV.



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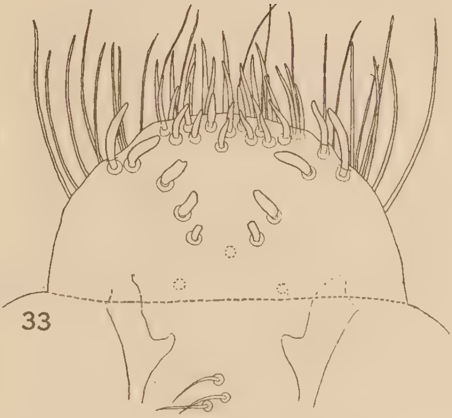

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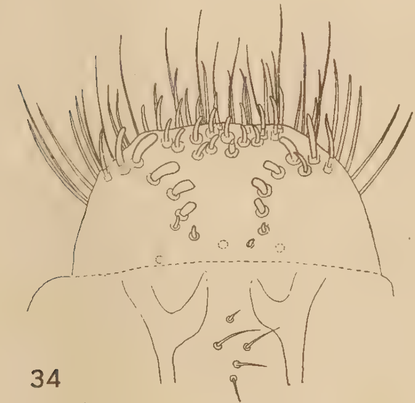

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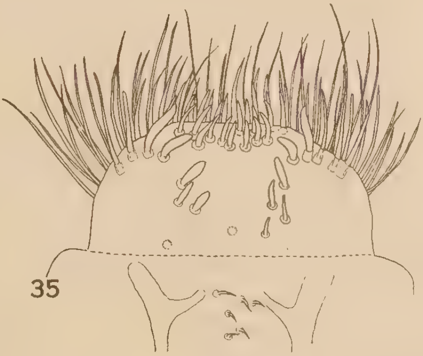

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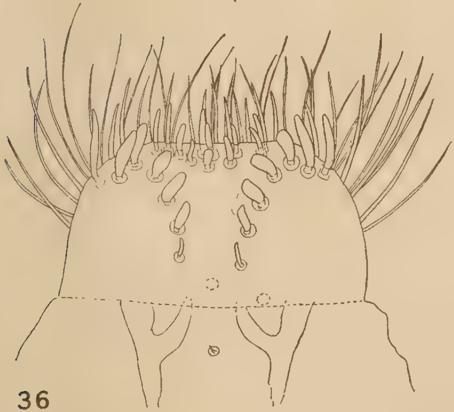

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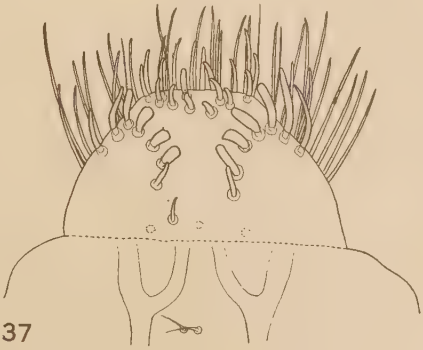

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EXPLANATION OF PLATE V.

Figs. 38–44.—Epipharynx, with labral sensillae seen through the epipharynx shown by dotted circles. The bases of the labral setae are not shown, but the parts of these setae projecting beyond the margin of the epipharynx are drawn. (38) *Ptinus tectus*. (39) *Gibbium psylloides*. (40) *Tipnus unicolor*. (41) *Stethomezium squamosum*. (42) *Ptinus* sp. indet. (43) *Trigonogenius globulus*. (44) *Niptus hololeucus*.

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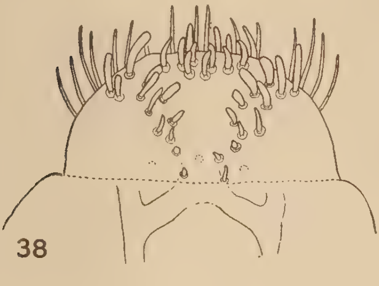
Plate V.



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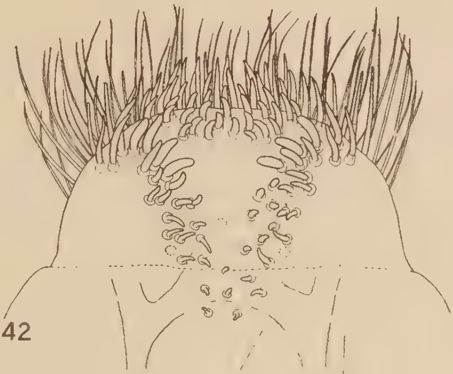

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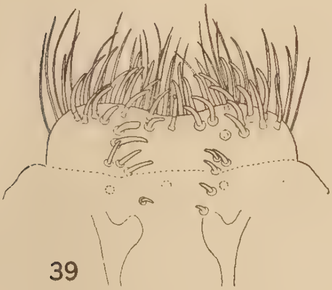

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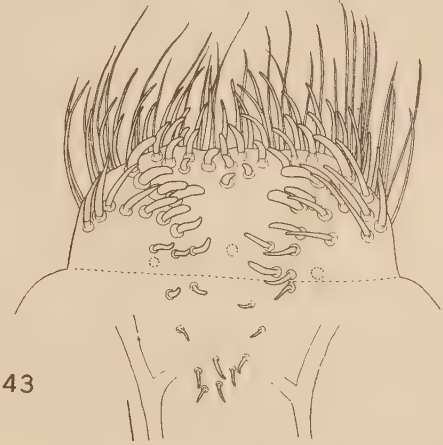

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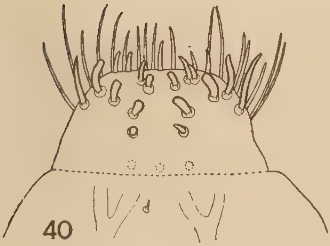

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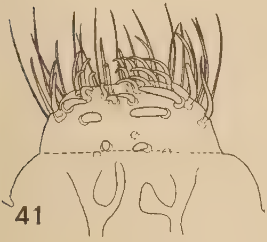

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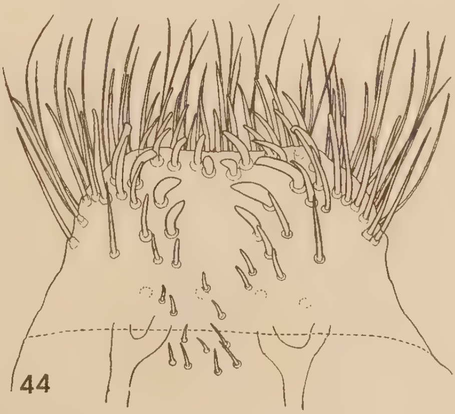


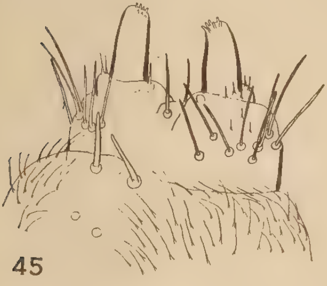
44

0·1 mm.

EXPLANATION OF PLATE VI.

FIGS. 45–56.—The upper Side of the Labium, the setae inserted on the lower surface are not shown: (45) *Ptinus latro.* (46) *P. hirtellus.* (47) *P. fur.* (48) *P. tectus.* (49) *P. pusillus* (*P. villiger* is very like this). (50) *P. raptor.* (51) *Tipnus unicolor.* (52) *Ptinus* sp. indet. (53) *Gibbium psylloides.* (54) *Trigonogenius globulus.* (55) *Stethomezium squamosum.* (56) *Niptus hololeucus.*

Bull. Ent. Research. Vol. 35. Plate VI.



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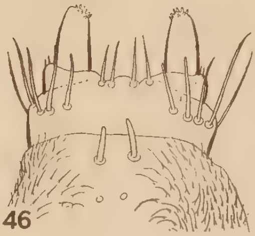

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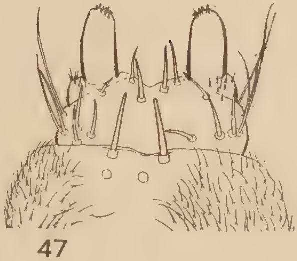

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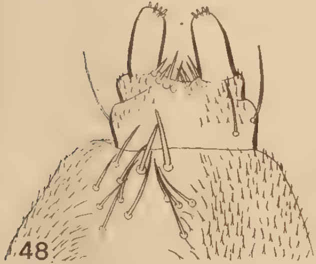

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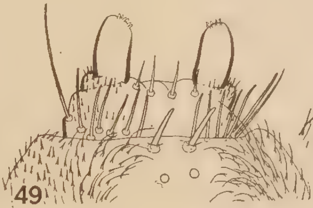

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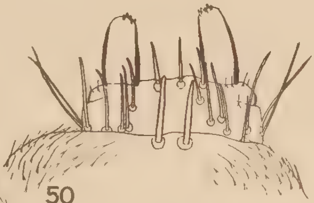

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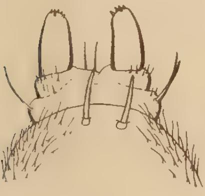

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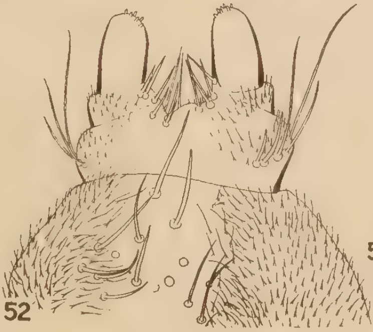

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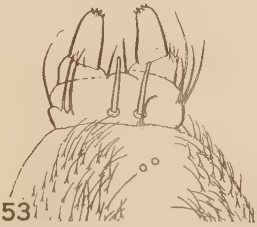

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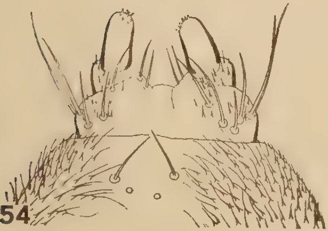

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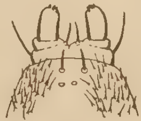

55

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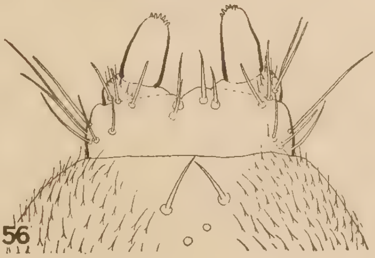

56

EXPLANATION OF PLATE VII.

FIGS. 57–60.—First Leg, posterior view of right limb, the setae on the anterior side, seen through the limb, are shown by dotted lines: (57) *Ptinus fur* (*P. tectus* and *Gibbium psylloides* are also like this). (58) *Ptinus* sp. indet. (59) *P. villiger.* (60) *P. raptor.*

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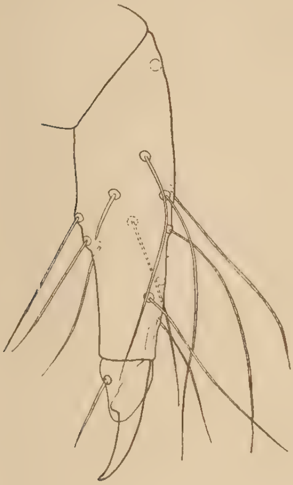
Plate VII.



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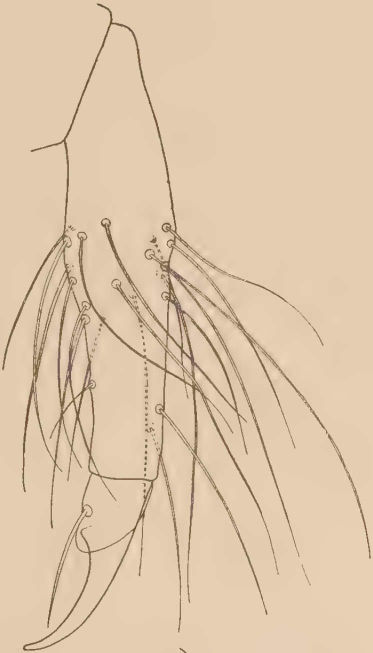

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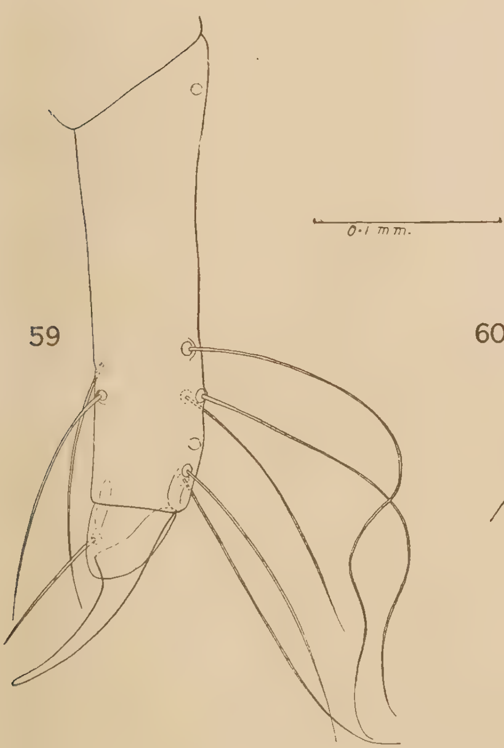

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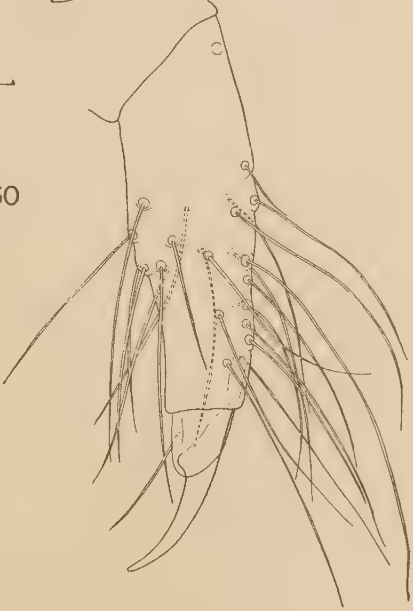

60

EXPLANATION OF PLATE VIII.

Figs. 61–65.—First Leg, posterior view of right limb, the setae on the anterior side, seen through the limb, are shown by dotted lines: (61) *Ptinus latro* (*P. pusillus* with 19-20 setae and *P. hirtellus* with 12-15 setae are also like this). (62) *Trigonogenius globulus.* (63) *Stethomezium squamosum.* (64) *Niptus hololeucus.* (65) *Tipnus unicolor.*

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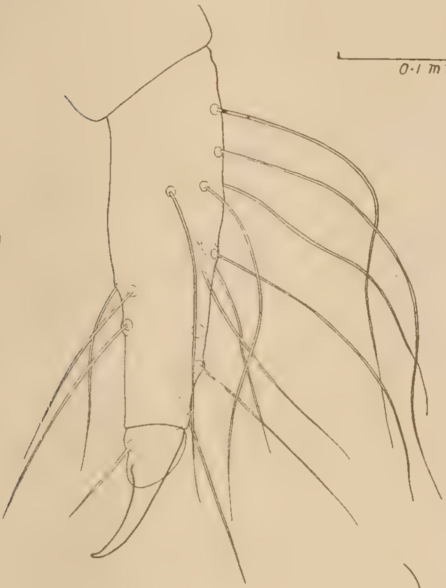

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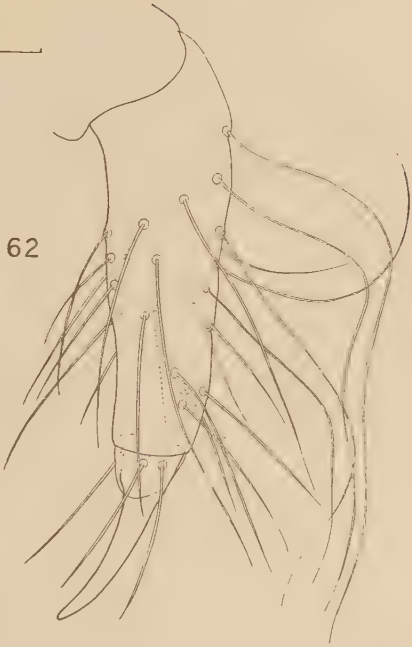

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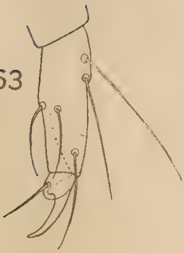

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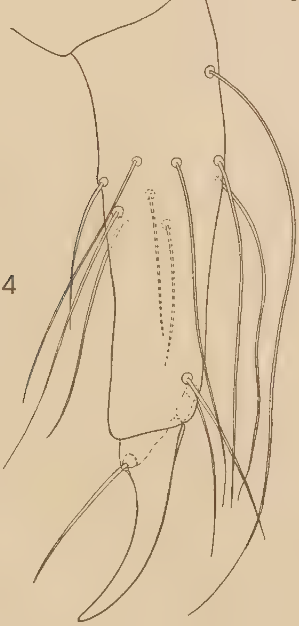

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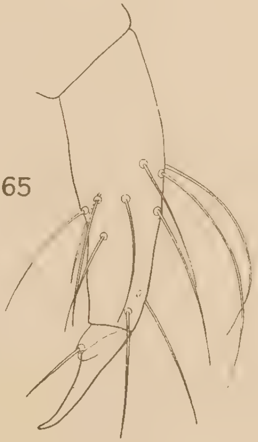
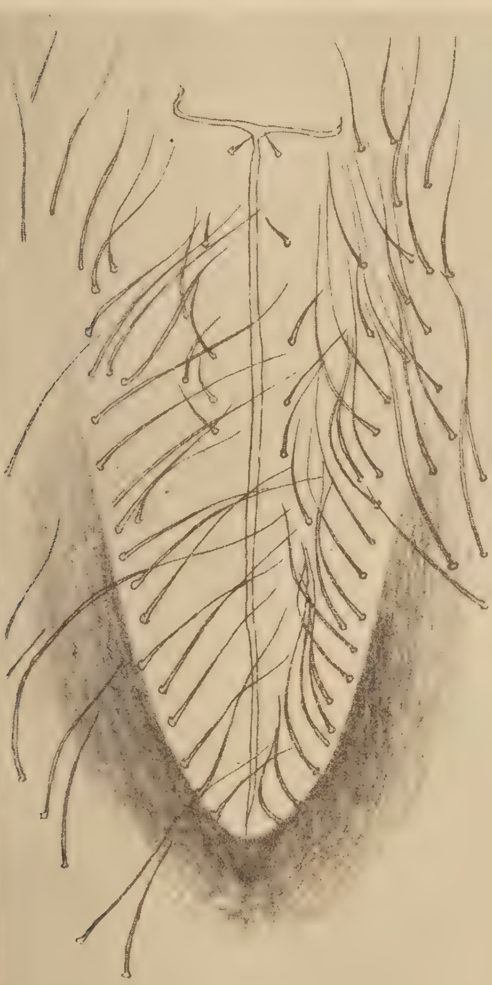


65

EXPLANATION OF PLATE IX.

Figs. 66–68.—Preanal Sclerite: (66) *Ptinus fur.* (67 & 68) Two Specimens of *Trigonogenius globulus.*



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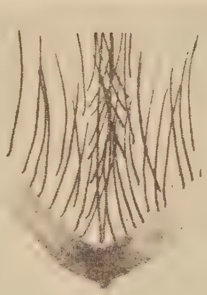

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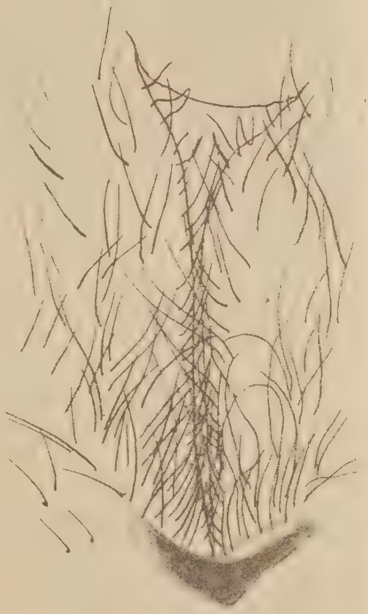

68

0·1 mm.

INSECT PESTS OF SOME ECONOMIC CROPS IN FIJI.

By R. J. A. W. Lever, B.Sc., D.I.C., A.I.C.T.A., F.L.S.

Entomologist, Department of Agriculture, Fiji.

E.M

Although a list of the insects associated with many Fijian trees and plants was published over an interval of twenty years in Australia (1-4), no handy one of the economic plants and their pests is known to the writer. This article has therefore been compiled to fill this gap and to allow comparison with similar lists published in the *Bulletin of Entomological Research* concerning East and West Africa and Palestine and in the agricultural journals of Malaya, Mauritius, Bermuda and Cyprus. It is recognised that this first list will require to be supplemented.

The writer is obliged to the Director of the Imperial Institute of Entomology, London, and to the Entomologists of the Hawaiian Sugar Planters' Association and of the Bishop Museum, Honolulu, for identification of the insects. The term economic plants is extended to include noxious weeds, but not jungle trees or ornamental plants. Only insects actually causing economic damage are included.

Geographical Position.

Fiji consists of a group of some 250 islands lying mostly between latitude 16° and 21° S., with an area of 7,000 square miles, of which the largest island accounts for 4,000 and the second largest for over 2,120 square miles. Fiji is included with the Solomon Islands and New Hebrides in Melanesia and has Polynesia (Samoa, Tonga and Society Islands, etc.) to the east. The highest point is on Viti Levu 4,300 feet. Most of the islands are surrounded by coral reefs. Hot springs occur, but no volcanos, though andesitic volcano plugs are common.

Climate.

The south-east trade is the dominant wind and blows from May to November; during the rest of the year the wind is variable in direction and intensity and often reaches hurricane force. The average annual rainfall varies from 60 to 85 inches in the dry zone and from 90 to 140 in the wet zone, in which is situated the capital, Suva, with an average rainfall of 120 inches. The mean temperature varies from 72° to 82°F., with an average of 78°F., and the mean relative humidity ranges from 72·5 to 84·5 per cent.

Ecology.

Forests occur chiefly in the south-east part of Viti Levu covering half its area and comprise a large proportion of the islands of Taveuni and Kadavu. Hardly any intensive collecting of insects has been done in the rain forests. Another large tract of country is grass plain with such dominant plants as *Casuarina equisetifolia*, *Pandanus odoratissimus*, the ferns, *Gleichenia* and *Pteris*, the reed, *Miscanthus japonicus*, and the ground orchid, *Spathoglottis pacifica*. Land is slowly being laid down in the mangrove deltas of the main rivers.

Chief Crops.

Sugar is the main agricultural export, with copra from the coconut palm second. Other important crops are bananas, taro or dalo, yams, breadfruit, tapioca, sweet potatoes, maize, rice and cotton. Fruits are citrus, pineapples, pawpaw, mango, passion fruit, granadilla and avocado pear. The usual temperate vegetables are also grown, potatoes being confined to the cooler areas.

1. CROPS.

Ananas comosus (Pineapple).
Anomocaulus fulvovestitus, Fairm. (Dynastid.)—Leaf, Stem, Flowers.
Carpophilus dimidiatus, F. (Nitidulid.)—Fruit.
Carpophilus hemipterus, L. (Nitidulid.)—Fruit.
Carpophilus humeralis, F. (Nitidulid.)—Fruit.
Carpophilus mutabilis, Fairm. (Nitidulid.)—Fruit.
Epuraea (*Haptoncus*) *luteola*, Erichson (Nitidulid.)—Fruit.
Haptoncus ocularis, Fairm. (Erichson)—Fruit.
Diaspis bromeliae, Kerner (Coccid.)—Leaf.
Pseudococcus brevipes, Ckll. (Coccid.)—Leaf.

Arachis hypogaea (Ground-nut).
Epilachna vigintioctopunctata, F. (Coccinellid.)—Leaf.

Artocarpus communis (incisa) (Breadfruit).
Dacus (*Notodacus*) *xanthodes*, Broun (Trypetid.)—Fruit.
Icerya seychellarum, Westw. (Coccid.)—Leaf.

Avocado see *Persea.*

Balsam Vine see *Momordica.*

Bamboo see *Schizostachyum.*

Banana see *Musa.*

Bean see *Phaseolus.*

Bean, Mauritius see *Mucuna.*

Beta vulgaris (Beet).
Hymenia recurvalis, F. (*fascialis*, Stoll) (Pyralid.)—Leaf.
Prodenia litura, F. (Noctuid.)—Leaf.

Brachiaria mutica (Para Grass).
Cirphis unipuncta, Haw. (Noctuid.)—Leaf.
Heliothis armigera, Hb. (Noctuid.)—Leaf.
Spodoptera mauritia, Boisd. (Noctuid.)—Leaf.

Brassica campestris (Turnip),
Brassica chinensis (Chinese Cabbage).
Agrotis ypsilon, Hfn. (Noctuid.)—Leaf.
Plusia chalcites, Esp. (Noctuid.)—Leaf.
Prodenia litura, F. (Noctuid.)—Leaf.
Crocidolomia binotalis, Zell. (Pyralid.)—Leaf.
Hellula undalis, F. (Pyralid.)—Leaf.
Plutella maculipennis, Curt. (Tineid.)—Leaf.
Liriomyza pusilla, Mg. (Agromyzid.)—Leaf.
Epilachna vigintioctopunctata, F. (Coccinellid.).

Breadfruit see *Artocarpus.*

Brinjal see *Solanum.*

Cabbage see *Brassica.*

Cajanus cajan (Pigeon Pea, Dhal).
Brachyplatys pacificus, Dall. (Pentatomid.)—Stem.
Nezara viridula, L., var. *smaragdula*, L. (Pentatomid.)—Pods.
Ceroplastes rubens, Mask. (Coccid.)—Stem.
Heliothis armigera, Hb. (Noctuid.)—Pods.
Labdia calida, Meyr. (Tineid.)—Pods.

Camellia sinensis (Tea).
Adoxophyes fasciculana, Wlk. (Tortricid.)—Leaf (roller).
Agromyza (*Melanagromyza*) *phaseoli*, Coq. (Agromyzid.)—Leaf (miner).

Carica papaya (Pawpaw).
Dacus (*Chaetodacus*) *passiflorae*, Frogg. (Trypetid.)—Fruit.
Dacus (*Notodacus*) *xanthodes*, Broun (Trypetid.)—Fruit.

Carrot see *Daucus.*

Castor see *Ricinus.*

Chestnut, Tahitian see *Inocarpus.*

Citrullus vulgaris (Water Melon).
Aulacophora quadrimaculata, F. (Galerucid.)—Leaf.

Citrus limonia (Lemon),
Citrus nobilis (Mandarin),
Citrus sinensis (Orange),
Citrus aurantiifolia (Lime).
Aphis citricidus, Kirk. (Aphid.)—Shoots.
Lepidosaphes beckii, Newm. (Coccid.)—Branch, Leaf, Fruit.
Prontaspis citri, Comst. (Coccid.)—Trunk, Branch, Leaf.
Pseudococcus citri, Risso (Coccid.)—Fruit.
Mictis profana, F. (Coreid.)—Shoots.
Othreis fullonia, Clerck (*fullonica*, L.) (Noctuid.)—Fruit.
Dacus (*Chaetodacus*) *passiflorae*, Frogg. (Trypetid.)—Fruit.
Rhinoscapha lagopyga, Fairm. (Curculionid.)—Leaf.

Clidemia hirta (Koster's Curse).
Liothrips urichi, Karny (Thysanoptera).

Cocoa see *Theobroma.*

Cocos nucifera (Coconut).
Acritocera negligens, Btlr. (Cossid.)—Spathe.
Agonoxena argaula, Meyr. (Tineid.)—Leaf.
Trachycentra calamias, Meyr. (Tineid.)—Cabbage.
Tirathaba trichogramma, Meyr. (Pyralid.)—Spathe.

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Aspidiotus destructor, Sign. (Coccid.)—Leaf.
Graeffea ~~*cocophaga*, Newp~~. (Phasmid.)—Leaf. crovani, Le Guill.
Diocalandra taitensis, Guér. (Curculionid.)—Spathe.
Promecotheca reichei, Baly (Hispid.)—Leaf (miner).
Xyleborus testaceus, Wlk. (Scolytid.)—Trunk.

Colocasia esculenta (Dalo, Taro).
Hippotion celerio, L. (Sphingid.)—Leaf.
Prodenia litura, F. (Noctuid.)—Leaf.
Aphis gossypii, Glov. (Aphid.)—Leaf.
Megamelus proserpina, Kirk. (Delphacid.)—Leaf Stalk

Cotton see *Gossypium.*

Cowpea see *Vigna.*

Crotalaria retusa,
Crotalaria mucronata.
Argina cribraria, Cl. (Hypsid.)—Leaf.
Maruca testulalis, Geyer (Pyralid.)—Pod.
Utetheisa pulchella, L. (Arctiid.)—Pod.

Cucumis sativus (Cucumber).
Aulacophora similis, Oliv. ~~*coffeae*, Hornstedt~~ (Galerucid.)—Leaf.

Cucurbita pepo (Marrow, Pumpkin).
Aulacophora similis, Oliv. ~~*coffeae*, Hornstedt~~ (Galerucid.)—Leaf.
Epilachna vigintioctopunctata, F. (Coccinellid.)—Leaf.
Leptoglossus australis, F. (Coreid.)—Shoots.
Margaronia indica, Saund. (Pyralid.)—Leaf.

Dalo see *Colocasia.*

Daucus carota (Carrot).
Prodenia litura, F. (Noctuid.)—Leaf.

Dawa see *Pometia.*

Dhal see *Cajanus.*

Dioscorea alata,
Dioscorea pentaphylla,
Dioscorea esculenta (Yams).
Aspidiella (*Aspidiotus*) *harti*, Ckll. (Coccid.). }
Pinnaspis minor, Mask. (Coccid.). } On tubers.
Prodenia litura, F. (Noctuid.)—Leaf.

Egg-plant see *Solanum melongena.*

Eugenia malaccensis (Malay Apple, Kavika).
Dacus (*Strumeta*) *passiflorae*, Frogg. (Trypetid.)—Fruit.
Megatrioza vitiensis, Kirk. (Psyllid.)—Leaf (gall).

Gossypium barbadense (Sea Island Cotton).
Aphis gossypii, Glov. (Aphid.)—Leaf, Seedlings, Shoots.
Dysdercus insularis, Stål (Pyrrhocorid.)—Leaf, Boll.
Dysdercus impictiventris, Stål (Pyrrhocorid.)—Leaf, Boll.
Empoasca quadripunctata, ~~Evans~~ Lever (Jassid.)—Leaf.
Nezara viridula, L. (Pentatomid.)—Boll.
Tectocoris diophthalmus, Thnb. (Pentatomid.)—Boll.
Cosmophila flava, F. (Noctuid.)—Leaf.
Earias fabia, Stoll (Noctuid.)—Stem, Branches, Boll.
Prodenia litura, F. (Noctuid.)—Leaf.

Gourd, Bitter see *Momordica.*

Granadilla see *Passiflora.*

Ground-nut see *Arachis.*

Guava see *Psidium.*

Hevea brasiliensis (Rubber).
Crossotarsus saundersi, Chap. (Platypodid.)—Bark.

Inocarpus edulis (Ivi, Tahitian Chestnut).
Argyroploce (*Cryptophlebia*) *illepida*, Btlr. (Tortricid.)—Fruit.
Cryptoblabes plagioleuca, Turn. (Pyralid.)—Leaf.
Striglina superior, Btlr. (Thyridid.)—Leaf.
Thalassodes pilaria, Gn. (Geometrid.)—Leaf.

Ipomoea batatas (Sweet Potato).
Herse convolvuli, L. (Sphingid.)—Leaf.
Hippotion celerio, L. (Sphingid.)—Leaf.
Hippotion velox, F. (Sphingid.)—Leaf.
Hymenia recurvalis, F. (Pyralid.)—Leaf.
Cylas formicarius, F. (Curculionid.)—Tuber.
Euscepes postfasciatus, Fairm. (Curculionid.)—Tuber.

Ivi see *Inocarpus.*

Kava see *Piper.*

Kavika see *Eugenia.*

Koster's Curse see *Clidemia.*

Lantana camara (aculeata).
Teleonemia scrupulosa, Stål (Tingid.)—Flower.
Thecla bazochii, Godt. (*agra*, Hew.) (Lycaenid.)—Flower.
Agromyza lantanae, Frogg. (Agromyzid.)—Seed.

Lemon see *Citrus.*

Lime see *Citrus.*

Lycopersicum esculentum (Tomato).
Agrotis ypsilon, Hfn. (Noctuid.)—Leaf.
Cosmophila flava, F. (Noctuid.)—Leaf.
Heliothis armigera, Hb. (Noctuid.)—Leaf.
Plusia chalcites, Esp. (Noctuid.)—Leaf.
Prodenia litura, F. (Noctuid.)—Leaf.
Epilachna vigintioctopunctata, F. (Coccinellid.)—Leaf.
Nezara viridula, L. (Pentatomid.)—Fruit.

Maize see *Zea.*

Malay Apple see *Eugenia.*

Mandarin see *Citrus.*

Marrow see *Cucurbita.*

Mauritius Bean see *Mucuna.*

Melon see *Citrullus.*

Momordica charantia (Bitter Gourd, Balsam Vine).
Heliothis armigera, Hb. (Noctuid.)—Fruit.

Mucuna aterrima (Mauritius Bean).
Argyroploce (*Cryptophlebia*) *illepida*, Btlr. (Tortricid.)—Seed.
Prodenia litura, F. (Noctuid.)—Leaf.
Brachyplatys pacificus, Dall. (Pentatomid.)—Stem.

Musa cavendishii,
Musa paradisiaca,
Musa sapientum (Banana, Plantain).
Cosmopolites sordidus, Germ. (Curculionid.)—Corm.
Nacoleia octasema, Meyr. (Pyralid.)—Fruit.
Trachycentra calamias, Meyr. (Tineid.)—Stem.
Pentalonia nigronervosa, Coq. (Aphid.)—Leaf.

Nicotiana tabacum (Tobacco).
Engytatus tenuis, Reut. (Capsid.)—Leaf.
Epilachna vigintioctopunctata, F. (Coccinellid.)—Leaf.
Agrotis ypsilon, Hfn. (Noctuid.)—Leaf.
Heliothis armigera, Hb. (Noctuid.)—Seed Capsule.
Prodenia litura, F. (Noctuid.)—Leaf.
Gnorimoschema heliopa, Lower (Tineid.)—Stem.
Gnorimoschema (*Phthorimaea*) *operculella*, Zell. (Tineid.)—Leaf (miner).

Orange see *Citrus.*

Oryza sativa (Rice).
Cirphis unipuncta, Haw. (Noctuid.)—Flower, Leaf.
Spodoptera mauritia, Boisd. (Noctuid.)—Leaf.
Chilo simplex, Btlr. (Pyralid.)—Stalk.
Leptocorisa varicornis, F. (Coreid.)—Flower.
Sogata furcifera, Horv. (Delphacid.)—Leaf.

Pandanus thurstonii (Voivoi, Screw Pine).
Aeolarchis sphenotoma, Meyr. (Tineid.)—Leaf.
Trachycentra chlorogramma, Meyr. (Tineid.)—Leaf.

Para Grass see *Brachiaria.*

Passiflora quadrangularis (Granadilla).
Dacus (*Strumeta, Chaetodacus*) *passiflorae*, Frogg. (Trypetid.)—Fruit.
Dacus (*Notodacus*) *xanthodes*, Broun (Trypetid.)—Fruit.
Nezara viridula, L. (Pentatomid.)—Flower.

Pawpaw see *Carica.*

Pea see *Pisum* and *Vigna.*

Persea americana (Avocado Pear).
Xyleborus morstatti, Hag. (Scolytid.)—Trunk.
Xylothrips religiosus, Boisd. (Bostrychid.)—Branch.
Crossotarsus saundersi, Chap. (Platypodid.)—Branch.
Icerya seychellarum, Westw. (Coccid.)—Leaf.

Phaseolus calcaratus (Rice Bean).
Anticarsia irrorata, F. (Noctuid.)—Leaf.
Plusia chalcites, Esp. (Noctuid.)—Leaf.

Phaseolus vulgaris (French Bean),
Phaseolus lunatus (Lima Bean).
Brachyplatys pacificus, Dall. (Pentatomid.)
Zizera labradus, Godt. (Lycaenid.)—Flower.
Nacoleia diemenalis, Guen. (Pyralid.)—Leaf. A leaf roller.
Maruca testulalis, Geyer (Pyralid.)—Pod.

Pigeon Pea see *Cajanus.*

Pineapple see *Ananas.*

Piper (Macropiper) methysticum (Yagona, Kava).
Elytrurus smaragdus, Mshl. (Curculionid.)—Leaf.
Brachylybas variegatus, Le Guillou (Coreid.)—Stem.
Aspidiotus destructor, Sign. (Coccid.)—Stem.

Pisum sativum (Garden Pea).
Nezara viridula, L. (Pentatomid.)—Pod.
Heliothis armigera, Hb. (Noctuid.)—Pod.

Plantain see *Musa.*

Pometia pinnata (Dawa, Polynesian Plum).
Dacus (*Chaetodacus, Strumeta*) *passiflorae*, Frogg. (Trypetid.)—Fruit.

Potato see *Solanum.*

Potato, Sweet see *Ipomoea.*

Psidium guajava (Guava).
Dacus (*Chaetodacus, Strumeta*) *passiflorae,* Frogg. (Trypetid.)—Fruit.
Icerya seychellarum, Westw. (Coccid.)—Leaf, Shoot.
Adoxophyes fasciculana, Wlk. (Tortricid.)—Leaf (roller).
Spilonota holotephras, Meyr. (Tortricid.)—Leaf (roller).

Pumpkin see *Cucurbita.*

Raphanus sativus (Radish).
Crocidolomia binotalis, Zell. (Pyralid.)—Leaf.

Rice see *Oryza.*

Ricinus communis (Castor).
Achaea janata, L. (Noctuid.)—Leaf.

Rubber see *Hevea.*

Saccharum officinarum (Sugar-cane).
Cirphis unipuncta, Haw. (Noctuid.)—Leaf.
Prodenia litura, F. (Noctuid.)—Leaf.
Melanitis leda, L. (Satyrid.)—Leaf.
Trachycentra calamias, Meyr. (Tineid.)—Stalk.
Trachycentra chlorogramma, Meyr. (Tineid.)—Stalk.
~~*Brachyplatys pacificus,* Dall. (Pentatomid.)—Leaf.~~
Perkinsiella vitiensis, Kirk. (Delphacid.)—Leaf.
Pseudococcus brevipes, Ckll. (*bromeliae,* auct.) (Coccid.)—Stalk.
Rhopaea subnitida, Arrow (Melolonthid.)—Root.
Rhopaea vestita, Arrow (Melolonthid.)—Root.
Rhabdoscelus (*Rhabdocnemis*) *obscurus,* Boisd. (Curculionid.)—Stalk.

Schizostachyum glaucifolium (Bamboo).
Dinoderus minutus, F. (Bostrychid.)—Stalk (internodes).

Screw Pine see *Pandanus.*

Solanum melongena (Egg-plant, Brinjal).
Prodenia litura, F. (Noctuid.)—Leaf.
Epilachna vigintioctopunctata, F. (Coccinellid.)—Leaf.
Lygus muiri, Poppius (Capsid.)—Leaf.

Solanum tuberosum (Potato).
Gnorimoschema (*Phthorimaea*) *operculella,* Zell. (Tineid.)—Leaf, Tuber.
Epilachna vigintioctopunctata, F. (Coccinellid.)—Leaf.

Spinacia oleracea (Spinach).
Crocidolomia binotalis, Zell. (Pyralid.)—Leaf.
Hymenia recurvalis, F. (Pyralid.)—Leaf.

Sugar-cane see *Saccharum.*

Sweet Potato see *Ipomoea.*

Taro see *Colocasia.*

Tea see *Camellia*.

Theobroma cacao (Cocoa).
Adoretus versutus, Har. (Rutelid.)—Leaf.
Xylopsocus castanoptera, Fairm. (Bostrychid.)—Trunk, Branch.
Xylothrips religiosus, Boisd. (Bostrychid.)—Trunk, Branch.

Tobacco see *Nicotiana*.

Tomato see *Lycopersicum*.

Turnip see *Brassica*.

Vigna unguiculata (sinensis) (Cowpea).
Dracaenura pelochra, Meyr. (Pyralid.)—Leaf.
Maruca testulalis, Geyer (Pyralid.)—Pod.
Plusia chalcites, Esp. (Noctuid.)—Leaf.
Zizera labradus, Godt. (Lycaenid.)—Flower.
Nezara viridula, L. (Pentatomid.)—Pod.

Voivoi see *Pandanus*.

Yagona see *Piper*.

Yam see *Dioscorea*.

Zea mays (Maize).
Aphis maidis, Fitch (Aphid.)—Leaf, Stalk.
Peregrinus maidis, Ashm. (Delphacid.)—Leaf.
Cirphis unipuncta, Haw. (Noctuid.)—Leaf.
Heliothis armigera, Hb. (Noctuid.)—Cob.
Prodenia litura, F. (Noctuid.)—Leaf.
Spodoptera mauritia, Boisd. (Noctuid.)—Leaf.
Phytomyza spicata, Mall. (Agromyzid.)—Leaf (miner).

2. STORED PRODUCTS.

Beans.
Bruchus (Bruchidius) obtectus, Say (Bruchid.).

Chocolate.
Corcyra cephalonica, Staint. (Pyralid.).

Cigars.
Lasioderma serricorne, F. (Anobiid.).

Copra.
Ephestia cautella, Wlk. (Pyralid.).
Necrobia rufipes, Deg. (Clerid.).
Scholastes bimaculatus, Hend. (Ortalid.).

Cotton.
Corcyra cephalonica, Staint. (Pyralid.).

Cowpea.
Bruchus tristiculus, Fhs. (Bruchid.).

Cumin.
Sitodrepa panicea, L. (Anobiid.).

Derris (*D. elliptica*).
Minthea rugicollis, Wlk. (Lyctid.)—Root.
Xylothrips religiosus, Boisd. (Bostrychid.)—Root.

Maize.
Araecerus fasciculatus, Deg. (Anthribid.).
Calandra oryzae, L. (Curculionid.).
Corcyra cephalonica, Staint. (Pyralid.).
Ephestia cautella, Wlk. (Pyralid.).
Sitotroga cerealella, Ol. (Tineid.).

Oatmeal and Flour.
Tribolium castaneum, Hbst. (Tenebrionid.).
Rhizopertha dominica, F. (Bostrychid.).
Laemophloeus minutus, Ol. (Cucujid.).
Corcyra cephalonica, Staint. (Pyralid.).

Pigeon Pea.
Bruchus chinensis, L. (Bruchid.).
Ephestia cautella, Wlk. (Pyralid.).

Raisins.
Ephestia cautella, Wlk. (Pyralid.).

Rice.
Alphitobius diaperinus, Panz. (Tenebrionid.).
Tribolium castaneum, Hbst. (Tenebrionid.).
Calandra oryzae, L. (Curculionid.).
Carpophilus dimidiatus, F. (Nitidulid.).
Oryzaephilus surinamensis, L. (Cucujid.).
Rhizopertha dominica, F. (Bostrychid.).
Tenebroides mauritanicus, L. (Trogositid.).
Corcyra cephalonica, Staint. (Pyralid.).
Sitotroga cerealella, Ol. (Tineid.).

Rice Bran.
Alphitobius laevigatus, F. (Tenebrionid.).
Necrobia rufipes, Deg. (Clerid.).

Soya Bean.
Setomorpha rutella, Zell. (Tineid.).
Tinea chlorospora, Meyr. (Tineid.).
Laemophloeus minutus, Ol. (Cucujid.).

Tobacco (Leaf, Dried Pods).
Lasioderma serricorne, F. (Anobiid.).

3. MISCELLANEOUS MATERIALS.

Books and Papers.

Catorama herbarium, Gorh. (Anobiid.).
Orphinus aethiops, Arrow (Dermestid.).
Acrotelsa sp. (Thysanura).
Supella supellectilium, Serv. (Blattid.).

Clothing.

Tinea pellionella, L. (Tineid.).
Tineola uterella, Wlsm. (Tineid.).

Gum.

Alphitobius diaperinus, Panz. (Tenebrionid.).

Pith Helmet.

Erechthias zebrina, Btlr. (Tineid.).

Timber (Dressed).

Coptotermes acinaciformis, Frogg. (Isoptera).
Kalotermes buxtoni, Hill (Isoptera).
Kalotermes repandus, Hill (Isoptera).
Prorhinotermes inopinatus, Silv. (Isoptera).

Wire, Insulating.

Anthrenus fasciatus, Hbst. (~~Anthribid~~.). / Dermestid

The writer is obliged to Mr. W. Greenwood, F.L.S., of Lautoka, for help with plant synonyms, and for assistance with records of insect damage. The names of plants are those used by Sampson (7).

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SOME DIFFERENCES IN THE PHYSIOLOGY AND ECOLOGY OF LOCUSTS AND GRASSHOPPERS.

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Introduction.

In his book on " Locusts and Grasshoppers " Uvarov (1928) classified injurious Acridids into two categories on the basis of their behaviour. According to this definition, a locust is characterised by a tendency for the nymphs and adults to become gregarious as the density of the population increases; and the gregarious bands of hoppers and swarms of adults may undertake organised mass migrations. The grasshopper, on the other hand, is non-gregarious and non-migratory. Uvarov pointed out (p. 88 *et seq.*) that this classification was not based on fundamental differences between the two groups and stressed the need for further work, particularly on the physiology and ecology of the species grouped as grasshoppers.

Although it is possible to classify injurious Acridids in this way and to find striking differences at the extremes of the two categories, the classification is nevertheless artificial and unsatisfactory. Behaviour is not independent of environment; the locust, in between outbreaks, behaves as a solitary grasshopper; many species of plague grasshoppers become gregarious during mass outbreaks, and frequently undertake organised migrations in the nymphal stage; some species even tend to form migratory swarms of adults, *e.g.*, *Melanoplus mexicanus* (Shotwell, 1938) and *Acropus sibiricus* (Rubtzov, 1935). Furthermore, the morphological differences between the phases *gregaria* and *solitaria*, which have been considered to be characteristic of locusts, also occur in certain grasshoppers, *e.g.*, *M. mexicanus* (Faure, 1933) and various Siberian species (Rubtzov, 1938).

A great deal of work has been done in this field since 1928, and it is now possible to divide the injurious ACRIDIDAE into two major groups on the basis of physiological and ecological characters. It is convenient to retain the names " locust " and " grasshopper," particularly as this classification runs nearly parallel with the older one based on behaviour.

The two groups have become specialised along different lines. The gregarious and migratory characters are most fully developed in the locusts, although most grasshoppers show at least the beginnings of specialisation in this direction. The presence of diapause in the egg-stage of grasshoppers represents a high degree of specialisation, whereas the locusts are more primitive with respect to this character.

Locusts.

(a) *Geographical Distribution.*

Locusts (in contrast with grasshoppers) characteristically have a wide geographical distribution, extending over diverse climatic zones. The solitary phase of *Chortoicetes terminifera* may be found, permanently established, throughout most of southern Australia; during outbreaks, plagues infest most of this area (Key, 1938). This is an area which includes diverse climatic zones (Davidson, 1936). Plagues of *Schistocerca gregaria* have been recorded from almost the whole of Africa and south-western Asia (Uvarov, 1928). The extraordinarily wide distribution of plagues of *Locusta migratoria* is illustrated by the map published by Uvarov on page 240. Even when allowance is made for the fact that *L. migratoria* may be divided into a number of races, the diversity of the climate in the areas which may be infested by plagues of this species is most striking.

The areas in which swarms may arise are more restricted. With *L. migratoria*, swarms develop only in the tropics (*e.g.*, West Africa, Northern Australia) or in regions where the summer is hot and where lakes and river beds may provide a specially humid (sub-tropical) micro-environment. Thus in central Asia around the Caspian and Aral seas the mean temperature for January may be 20-50°F., but the mean temperature for July may be 75-90°F. In the specialised habitats of the reedbeds associated with the rivers there is adequate moisture during the summer for mass multiplication of the locust. The known outbreak areas for *S. gregaria* are located in desert or semi-arid areas in low latitudes (Zone 3 of Trewartha, 1937). The limiting climatic factor is rainfall, since temperature is adequate for growth at all times of the year (Bodenheimer, 1935). Outbreak areas probably occur all along the coasts of north-eastern Africa and western Asia wherever the winter rainfall for some years may exceed 9 inches (Maxwell-Darling, 1936). The outbreak areas for *Locustana pardalina* are located in south-western Africa in a climatic zone where the mean temperature for January is 70-85°F. and the mean annual rainfall is 10-15 inches; about 90 per cent. of the rain falls between September and April (du Plessis, 1938). The major outbreak area for *C. terminifera* is located in eastern Australia between latitudes 28° and 32° S. (Key, 1938). In this area the mean temperature for January is 70-80°F.; the mean minimum monthly temperature exceeds 60°F. for the period November to April. The annual rainfall is between 15 and 25 inches; slightly more than 70 per cent. of this falls between September and April. The species does not multiply to plague numbers further south where the climate is of the warm, temperate (Mediterranean) type, with most of the rain falling in the winter, and with the summer hot and dry. But a minor outbreak area is associated with the lower Murray River, in the vicinity of Renmark, where floodwaters create local favourable habitats in an area that is normally too dry in summer and too cold in winter to favour the mass multiplication of the locust (Andrewartha, 1940).

The scanty data which are available for other species also fit into this picture, namely that outbreak centres are restricted to tropical or semi-tropical climates where adequate rainfall coincides with high temperature, or to warm arid areas where rivers create special habitats where moisture is adequate during the summer.

(b) *Factors favouring Multiplication.*

The multiplication of *Chortoicetes terminifera* is favoured by rain above the average during the period September to April, particularly if it is evenly distributed through the season, enabling generations to succeed each other continuously. Given favourable warmth and moisture, the locust may complete three generations between September and April (Key, 1942, 1943). With *Locustana pardalina* dry seasons do not favour multiplication. Swarms may develop in the outbreak areas when average, or above-average, rainfall has been evenly distributed through the eight warm months of the year (*i.e.*, from September to April). In one area 13 generations developed during the four years from 1930/31-1933/34 (du Plessis, 1938). Precise information is not available for any other species, but with *Schistocerca gregaria* swarms probably develop as a result of rainfall above the average in the outbreak areas (Husain & others, 1940; Maxwell-Darling, 1936; Bodenheimer, 1932).

Although above-average rainfall in the outbreak areas favours the multiplication of *C. terminifera* there is a point beyond which excessive humidity becomes unfavourable and may destroy the incipient swarms (Key, 1942, 1943). Precise information about the influence of excessive humidity in the outbreak areas on other species is not available, but it may be inferred that the same applies to *L. pardalina,* since swarms do not develop in areas where the annual rainfall exceeds 20 inches (du Plessis, 1938); and to *S. gregaria* since the more humid southern parts of the Anglo-Egyptian Sudan are less favourable than the more arid northern parts (Maxwell-Darling, 1936). The destruction of swarms in the invasion areas by excessive humidity has been recognised for most, if not all, the species.

From the above information, it may be inferred that (1) locusts multiply to plague numbers in "outbreak areas" which are often more arid than the "invasion areas" which the swarms subsequently invade, (2) the outbreak areas are located either in the tropics or in areas where the summer is hot and not excessively arid, (3) in the outbreak areas increase in numbers is favoured by average (or above-average) rainfall well-distributed through the warm season, and (4) under favourable conditions generations may follow each other continuously, so that a number of generations may develop in one season. The potentiality for a large increase in numbers during a favourable cycle of weather, lasting for several years, is self-evident. This potentiality exists because the locust (unlike the grasshopper) lays eggs, which, given adequate warmth and moisture, can develop without interruption from the time of being laid to the eclosion of the nymph.

(c) *The Absence of Diapause.*

With *Chortoicetes terminifera,* when the eggs were kept at 30°C., the nymphs emerged 19 days after the eggs had been laid (Swan, unpublished data). With *Locustana pardalina,* when eggs were incubated at 31°C., the nymphs emerged about 10 days after the eggs had been laid (Faure, 1932). In the field the period varied from 8-17 days when mean air temperature was of the order 15-20°C. (Smit, 1939). The eggs of *Nomadacris septemfasciata* required 21 days at 35°C. and 23·5 days at 32·2°C. In the field they normally hatched 4-6 weeks after they were laid (Faure, 1935). Nymphs of *Schistocerca gregaria* emerged 11 days after the eggs had been laid when these were kept in moist soil at 40°C. (Husain & Ahmad, 1936). With *Locusta migratoria,* the nymphs hatched 12·6 days after the eggs had been laid when they were incubated at 35°C. (Hamilton, 1936). It is clear that diapause does not occur in the egg-stage of any of these species.

With *Locustana pardalina* partly developed eggs remained alive, but dormant, for several years in dry soil; they resumed their development when the soil was re-moistened (Faure, 1932). The eggs of *Schistocerca gregaria* remained alive for 80 days in dry soil and resumed their development when the soil was re-moistened (Husain & others, 1940). The eggs of *Chortoicetes terminifera* retained their vitality for several months when stored in dry soil in a glasshouse; the nymphs emerged about a week after the soil had been re-moistened (Swan, unpublished data). In these cases the development of the eggs was inhibited by insufficient moisture; but there is no evidence of true embryonic diapause with any of these species.

Relatively high atmospheric humidity is necessary for the continuous development of the nymphs and adults of *Chortoicetes terminifera.* Swan (unpublished data) found that development was continuous through 7 or 8 generations when the locusts were kept in a cage in a humid glasshouse, but if the humidity were not maintained above about 70 per cent. the insects either failed to reach sexual maturity or took longer to reach the egg-laying stage. With *Schistocerca gregaria* and *Locusta migratoria,* both the survival rate for nymphs and the rate of maturation of adults fell off markedly below about 60-70 per cent. relative humidity. At optimum humidity and at 32·2°C., **S. gregaria** was bred continuously in cages for 4 successive generations and *L. migratoria* for 5 generations.

In nature *S. gregaria* and *L. migratoria* may remain sexually immature throughout the dry season and undertake oviposition only after the onset of the wet season (Maxwell-Darling, 1936; Faure, 1935). This has been called an imaginal diapause but it may be a simple inhibition of development due to insufficient humidity.

There is nothing in the literature to indicate that true diapause occurs in any stage of any of the 5 species discussed in the preceding paragraphs. With *Locustana pardalina* between 5 and 10 per cent. of the eggs did not give rise to nymphs at the first incubation. The eggs remained dormant at room temperature for several months during the summer; the nymphs emerged when the eggs were re-moistened and incubated (Faure, 1932). Details of the development of the embryos in these eggs are not available, but observations probably indicate that an incipient diapause occurs in the egg-stage of a small proportion of the eggs of *L. pardalina*. A true embryonic diapause probably occurs in *Dociostaurus maroccanus* and *Calliptamus italicus*; these two species have been classified as locusts but they should be regarded as plague grasshoppers in which gregarious and migratory characters are relatively strongly developed.

Plague Grasshoppers.

(a) *Geographical Distribution.*

Swarms of *Austroicetes cruciata* may occur over large areas in south-western and south-eastern Australia. Although the areas are large, they are nevertheless restricted to a definite climatic belt, the limits of which can be defined with precision (Andrewartha, 1944a). The wider region, of which the " grasshopper " belt forms a part, experiences a warm temperature (Mediterranean) type of climate. The summer is hot and arid, the winter mild and humid. The region may be sub-divided into a number of " bioclimatic zones " based on the duration of the rainy season, taking due account of both rainfall and evaporation. Broadly these bioclimatic zones run parallel with the coast; both the amount of rainfall and the duration of the rainy season decrease inland from the coast (Davidson, 1936). The climatic zone in which swarms normally occur is bounded on its northern (drier) side by an area in which the normal value for P/E ratio for the month when the nymphs reach maturity is 0·25; and on it southern (more humid) side by an area in which the normal value for P/E ratio for the month when the nymphs hatch is 1·0.* The location of the boundaries of this zone may fluctuate from year to year and the area infested by swarms of *A. cruciata* may increase or diminish in size or change its location accordingly. An example of this occurred in Western Australia during the period 1935-42 (Andrewartha, 1944a). Within the favourable climatic zone, plagues of the grasshopper may occur quite frequently (Jenkins, 1937; Key, 1938; Andrewartha, 1937; Birch & Andrewartha, 1941). In between outbreaks solitary individuals may be found over the whole area and swarms result from the multiplication of their progeny during a cycle of favourable seasons.

Grasshoppers do a great deal of damage to crops and pastures in North America. Twelve injurious species are listed by Shotwell (1941). Five of these are responsible for over 90 per cent. of the damage to all cultivated crops. In addition there are three other species which, together with two not mentioned by Shotwell, constitute a group of five which are recognised as the species which are most injurious to range and pasture plants (Parker, 1939). Thus in this area there is a group of at least 14 species which do serious damage; of these 10 may be selected out for special reference as major pests of cultivated crops and pastures.

The precise geographical distribution of each of these 10 species with reference to climate is not available from the literature, but Parker (1939) has published a map showing that grasshopper plagues are restricted to the western two-thirds of the United States. The " grasshopper belt " is situated in the " middle latitude steppe " and the western (drier) parts of the " humid microthermal " zones (Trewartha, 1937). In the east the boundaries of the " grasshopper belt " are parallel with the boundaries of the " humid microthermal " and the " humid subtropical " zones. In the west grasshopper plagues apparently do not develop in the " middle latitude " or " low latitude " desert nor in the " mediterranean " or " marine west coast " climatic zones. Within the favourable zone the different species tend to have restricted distributions. Thus plagues of *Melanoplus differentialis* mostly develop in the southern States of the " grasshopper belt "; and the species is rarely found north of the southern counties of North Dakota and Minnesota. On the other hand, *Camnula pellucida* is restricted to Canada and the more northern States of the U.S.A. It is seldom found in the more southern States. Plagues of *M. mexicanus* occur over a wider area but are more common in the northern Great Plains and Rocky Mountain States (Parker, 1939). Apparently in North America the distribution of plagues of grasshoppers is closely related to the distribution of climatic zones.

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* There is only one generation in a year so the various stages are present at the same season each year. (*See* below, p. 384.)

Some confusion exists regarding the extent to which these species are migratory. Dense, strongly migratory bands of nymphs may be formed by *Melanoplus mexicanus, Camnula pellucida* and *Dissosteira longipennis* (Parker, 1939). Adults of *M. mexicanus* have been known to infest, within one season, new territory located 50 to 100 miles from the hatching grounds; *M. differentialis* has been known to spread 100 miles beyond its normal limits. But it is clear that the infestation of new areas by organised mass flights is not important even with these species. Plagues normally develop as a result of the multiplication of the progeny of the solitary individuals within the area (Shotwell, 1938; Criddle, 1933).

A large area of Siberia is liable to be infested by plagues of grasshoppers. Rubtzov (1935) listed 25 common species from one locality, of which at least six are major pests (Rubtzov, 1932). The climate of this area is similar to that of the " grasshopper belt " of North America. That is the " middle latitude steppe " and the drier parts of the " humid microthermal " climatic zones of Trewartha are represented. The annual rainfall in the " grasshopper belt " in Siberia is about 10 inches; and those areas where the monthly totals for May and September do not exceed 1·2 inches are more particularly favourable. Plagues develop only rarely where the annual rainfall is between 11·5 and 14 inches and never where it exceeds 18 inches (Rubtzov, 1939).

The distribution of plagues of the various species within this wider zone is restricted by climate and may be interpreted by reference to an " aridity index," P/E, where P is the mean annual rainfall and E is the sum of the average monthly temperatures above 6°C. for the warm half of the year (Rubtzov, 1938). Thus plagues of *Aeropus sibiricus* develop in areas where the value for the " aridity index " is about 8; the outbreak areas for *Stauroderus scalaris* and *Chorthippus albomarginatus* are more northerly where the index has the value of about 11; and plagues of *Pararcyptera microptera* develop in areas where this index has the value of about 5 (Rubtzov, 1935a). The location of the area infested by plagues of these xerophilous species may vary from year to year and, during an outbreak cycle, the area infested by plagues usually extends from east to west and from the centre to the periphery of the area most liable to infestation. These changes are interpreted in terms of a cycle in the weather rather than in terms of organised migrations of swarms of adults (Rubtzov, 1939).

Certain species, notably *Chorthippus biguttulus, C. apricarius* and *Pararcyptera microptera,* may form bands of nymphs which may undertake organised migrations. Adults of two species, *Aeropus sibiricus* and *C. albomarginatus* " during mass outbreaks have been occasionally observed to fly in swarms " (Rubtzov, 1935). It is clear that with the Siberian species, as with those in North America, migration does not play an important part in the building up of an outbreak, and that plagues develop as a result of an increase in the progeny of the individuals already in the area.

(b) *Factors favouring Multiplication.*

Excessive humidity, particularly during the late winter or early spring, when the young nymphs are present, may be harmful to *Austroicetes cruciata* (Andrewartha, 1944a); but excessive aridity, especially in the late spring, may also reduce the rate of increase or even put an end to an outbreak (Birch & Andrewartha, 1941). The rate of increase is therefore likely to be greatest when the early spring is not excessively humid and the rainfall during the spring is well distributed and extends well into the early summer. These conditions are most likely to be fulfilled during a cycle of years with sub-normal rainfall.

Plagues of *Aeropus sibiricus* may develop in the " reservations " in any year when the " aridity index " is as low as 8, and in the more humid areas bordering on reservations whenever the value for this index remains below 8 for two or more consecutive years. During the outbreak years of 1896-99 in the Nizhneudinsk area the aridity index was between 6 and 9 for large areas where the normal value is between 12-14. The outbreak in eastern Siberia in 1923-27 was also associated with a cycle of years of sub-normal rainfall. Similar observations have been made for other pest species associated with *A. sibiricus* (Rubtzov, 1935a, 1938).

Parker (1930) quotes several instances of the mass destruction of the nymphs of *Melanoplus mexicanus* and *Camnula pellucida* by excessive humidity and refers to other instances in literature where similar observations have been made for other species. He concludes (p. 121) " that excessive moisture, acting as a promoter of fungous and bacterial diseases is one of the greatest natural checks with which grasshoppers have to contend." Increase in numbers is likely to be greatest when the early spring (before the eggs hatch) is cool and humid (thus promoting plant growth) and the summer is hot and prolonged with adequate, but not excessive, rainfall (Parker, 1939). The distribution of rainfall and periods of high humidity is more important than the amount of rainfall. Nevertheless, outbreaks tend to be associated with years when rainfall is sub-normal because other factors (notably hot summer and late fall), which favour multiplication of the grasshoppers, tend to be associated with sub-normal rainfall (Jones, 1939).

From the information presented in the preceding paragraphs, it is clear that plagues of grasshoppers, as distinct from locusts, are restricted to well-defined relatively " narrow " climatic regions. In the interval between outbreaks, solitary individuals may be found throughout the area and plagues develop when the weather favours the survival of their progeny. Extensions or retractions of the area infested by plagues from year to year is the outcome of cycles in the weather and not of migration by gregarious swarms away from an " outbreak area."

Whereas outbreaks of locusts tend to develop during a cycle of years with above-average rainfall, outbreaks of grasshoppers are associated with cycles of years with sub-normal rainfall. This difference is related to the different ecological adaptations of the two groups. Swarms of locusts develop in outbreak areas which are normally more arid than the invasion areas, but with grasshoppers there is no such distinction between " outbreak area " and " invasion area." Between outbreaks the numbers of both locusts and grasshoppers are reduced to a minute fraction of the numbers present during plagues, but with the grasshoppers this reduction is relatively less because they are adapted to maintain a relatively high population throughout the climatic zone in which plagues may occur. The most important adaptation is the presence of diapause in the egg-stage which enables the grasshopper to spend the unfavourable season (usually the most humid season of the year) in the egg-stage.

(c) *Diapause in the Egg Stage.*

With *Austroicetes cruciata* there is only one generation in a year. This is ensured by the presence of an embryonic diapause which is eliminated only after the eggs have been exposed to the relatively low temperatures of the winter. In the field in South Australia the elimination of diapause is finally completed during June (Birch, 1942); and the eggs complete their development and hatch during the early spring (Andrewartha, 1944b). The presence of diapause thus inhibits the development of the embryos during the summer and autumn and ensures that the nymphs will not be present during the summer, when there would be no food for them, nor during the winter when temperature would be too low for their development and high humidity would favour the development of fungous and bacterial diseases. The importance of diapause to the species is emphasised by the discovery that there are two races of *A. cruciata,* each race inhabiting slightly different climatic zones. The minimum temperatures in the area where plagues occur in western Australia are higher than those in the grasshopper belt of eastern Australia. The two races differ in the temperature which is most favourable for the elimination of diapause. With the race from western Australia, diapause was eliminated most rapidly at 13°C. whereas 10°C. was the most favourable temperature for the elimination of diapause from the eggs of the race from eastern Australia (Andrewartha, 1943, 1944).

The eggs of *Aeropus sibiricus, Chrysochraon brachypterus* and *Omocestus viridulus* did not complete their development when they were kept in a warm room during the winter (Beĭ-Bienko, 1928). No more detailed information is available regarding the Siberian species, but it is known that a number of them have only one generation a year, which may indicate the presence of diapause* (Moritz, 1915; Ilenko, 1930; Kadzevich, 1935).

Apparently diapause occurs in all 12 American species studied by Shotwell (1941), but he gives no details concerning diapause nor the conditions necessary for its elimination. When the eggs of *Circotettix verruculatus* were kept at a temperature above " developmental zero " for 17 months only 1 per cent. hatched; the embryos in the remainder had not begun to undertake katatrepsis. If eggs that had reached this stage during the summer were exposed to out-of-door temperatures during the winter, they hatched normally when they were incubated. The eggs of several other species behaved similarly to those of *Circotettix;* so did those of *Arphia xanthoptera,* except that with the latter a greater number hatched during the period of 17 months in an incubator (Carothers, 1923). With *Melanoplus differentialis,* diapause normally sets in after about 21 days at 25°C. (Slifer, 1932). But when the eggs were exposed continuously to 28°C., about 30 per cent. hatched with a mean incubation period of about 150 days. Diapause was eliminated from eggs which had been exposed for 14 days at 28°C. when they were exposed to 10°C. for 30 days (Burdick, 1937). Once diapause was eliminated by exposure to 10°C., the remainder of the development was completed in 14 days at 25°C. (Slifer, 1932). With *M. mexicanus,* when eggs collected in Minnesota were exposed continuously to 27°C., 32°C., or 37°C., the percentage of nymphs that emerged at each temperature was 45, 40 and 37, respectively, and the mean incubation periods were 26, 32 and 46 days, respectively. Eggs that had been exposed to 0·8°C. hatched in a shorter time when returned to 32°C. (Parker, 1930). Apparently 60-70 per cent. of the eggs were affected by diapause, which was not eliminated during exposure to temperatures in the range 27-37°C. With the remaining 30-40 per cent., either there was no diapause or else diapause was present but was eliminated during the exposure to temperature in the range 27-37°C. Apparently diapause disappeared more rapidly at 27° than at 37°C. Exposure to low temperatures, between 0·8°C., or to out-of-door temperatures during the winter eliminated diapause from both types of eggs.

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* A great deal of work has been done on the ecology of Siberian grasshoppers but unfortunately most of this is not available in the original in Australia. The information for this paper has largely been taken from the excellent reviews which have appeared in the *Review of Applied Entomology.*

There is no diapause in the egg stage of *Chortophaga viridifasciata* and *Arphia sulphurea*—two species which are found in the grasshopper belt but are not serious pests. With these species the nymphs emerge in the summer shortly after the eggs are laid; they grow during the summer and hibernate either as fifth-instar nymphs or adults (Slifer, 1932a).

The Phylogeny of Diapause in Acrididae.

It is possible to recognize a series which starts with forms like *Austroicetes cruciata* and *Circotettix verruculatus* where all the eggs enter a pronounced diapause, which is not eliminated by exposure to temperature within the range at which the embryo develops, no matter how long the eggs may remain at these temperatures. The series continues through such forms as *Melanoplus differentialis* where some 30 per cent. of the eggs developed (albeit very slowly) to the hatching stage at temperatures within the developmental range; through such forms as *M. mexicanus,* where some 40 per cent. of the eggs hatched at temperatures within the developmental range, the diapause factor (in this 40 per cent. of the eggs) being evident chiefly by the longer time required for development at 37°C. compared with 27°C.,* and ends with such species as *Chortophaga viridifasciata* and the locusts.

It is possible that *Locustana pardalina* represents a connecting link between the grasshoppers of the *M. mexicanus* type and the locusts like *Schistocerca gregaria* and *Locusta migratoria,* because Faure (1932) has observed that 5-10 per cent. of the eggs did not give rise to nymphs at the first incubation, but apparently remained dormant until the eggs were re-moistened and incubated several months later. These observations may indicate an incipient diapause in a small proportion of the eggs of *Locustana pardalina.*

It has been suggested elsewhere (Andrewartha, 1943) that two distinct processes may be involved in the development of the eggs of ACRIDIDAE. One is concerned with the growth and development of the embryo, and the other with some " ripening " process in the yolk, which makes the yolk " available " as food for the embryo and at the same time modifies its physical nature in such a way that it becomes a favourable medium for the complicated movements of the embryo which are known as blastokinesis. With those species like *Chortoicetes terminifera* and *S. gregaria,* where there is no diapause, the two processes may be active concurrently and over the same temperature range. With such species as *A. cruciata* and *Circotettix verruculatus,* the two processes (although still intimately associated in the ontogeny of the embryo) require widely different temperatures for their optimum activity and the temperature range over which each is active does not overlap with that of the other.

The primitive condition is that found in the locusts, *e.g. Chortoicetes terminifera, Locusta migratoria* and others. The first hint of specialisation may be found in the locust, *Locustana pardalina*; the " diapause " in this case is, however, eliminated by exposure to temperatures of the same order as those which favour the development of the embryo. With the grasshopper, *M. mexicanus,* the differentiation has gone further but the ranges of favourable temperature for the two processes probably overlap quite markedly, particularly with a proportion of the eggs. The final stage in the differentiation is to be found in the grasshoppers of the *Austroicetes* and *Circotettix* type where the ranges of temperature for the two processes overlap hardly at all. This character is apparently plastic and therefore liable to be acted upon by the forces of natural selection. This is indicated by the presence of two strains of *A. cruciata,* which are adapted to two slightly different climatic zones and which differ in the range of temperature favourable for the elimination of diapause.

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* This phenomenon was also observed with eggs of *A. cruciata* from which diapause had been partially eliminated (Birch, 1942).

Plagues of *M. mexicanus* occur over a wider region with more diverse climate than most other species in North America (Parker, 1939). Dr. Parker in a letter has informed me that in Nebraska and Kansas a second generation of this species occurs when egg-laying begins early in the summer. In Arizona and south California four distinct generations may occur. In the northern States where there is only one generation in the year there is sometimes enough accumulated temperature units to lead one to expect hatching, but there are no records of it having happened in Montana or Dakota. These observations are provocative of the speculation that in *M. mexicanus* there are geographic races that differ in the extent to which diapause occurs in the egg stage, the northern race being more specialised and the southern race more primitive and therefore nearer to the locusts. This speculation gains interest because *M. mexicanus* is also the most gregarious and most migratory of the North American species (Shotwell, 1938).

The Status of Dociostaurus and Calliptamus.

Plagues of *Dociostaurus maroccanus* have been recorded from Spain, Italy, northern Africa, Asia Minor, parts of the Balkans and the Crimea. These are all areas with a warm temperate (Mediterranean) type of climate. The detailed distribution of plagues with reference to climate has not been established, but two detailed surveys by Uvarov (1932, 1933) in Anatolia, Syria, and Iraq have indicated that the area infested by plagues is restricted by climate, particularly rainfall. Thus in Syria swarms have not been reported outside the zone which lies between the 10″ and 20″ isohyets for annual rainfall.

During the period 1909-18, the area in Anatolia infested by plagues gradually increased in size. It is not known what weather was experienced during this period, but the picture presented by Uvarov (1932) for *Dociostaurus* in Anatolia is similar to that described by Rubtzov (1939) for certain Siberian species during an outbreak cycle. In Siberia such outbreaks are usually associated with a series of years with sub-normal rainfall.

The eggs of *D. maroccanus* are laid during May-June but they do not hatch until the following March-April. Uvarov (1932) interprets this prolonged dormant period as development inhibited first by drought and then by cold, but the observations could also be explained in terms of a diapause similar to that in *A. cruciata.*

There is a striking similarity between *D. maroccanus* and *A. cruciata* with respect to the climate of the zone where plagues occur, the seasonal life cycle, and the general ecological requirements of the nymphs and adults. So it is possible that further work with the biology and ecology of *D. maroccanus* may show that this species should be classified as a plague grasshopper and not as a locust.

Very little is known of the biology of *Calliptamus italicus.* Its distribution is similar to but wider than that of *D. maroccanus.* There is only one generation a year. It may be that this species too should be classified as a plague grasshopper and not as a locust.

Summary.

The known facts about the ecology of a number of the more important species of injurious ACRIDIDAE have been reviewed. The species fall naturally into two groups. The members of one group have the following characters:—

(*a*) The distribution of solitary individuals, and of plagues during outbreaks, extends over very wide areas with diverse climates.

(*b*) Plagues originate in " outbreak areas " which are often more arid than the " invasion areas ".

(*c*) Development of plagues in the outbreak area is favoured by a cycle of years with above-average rainfall.

(*d*) There is no true diapause in any stage; with favourable weather there may be several generations in one year.

(*e*) Development may be inhibited by dryness. Particularly development of nymphs and maturing of the reproductive organs may be retarded by inadequate atmospheric humidity.

The members of the second group have the following characters:—

(*a*) The distribution of plagues is restricted to well-defined, relatively " narrow " climatic zones.

(*b*) There is no clear distinction between " outbreak area " and " invasion area "; the species are adapted to maintain a relatively high population throughout the area where plagues may occur; and plagues develop when the weather favours the multiplication of individuals already in the area.

(*c*) Plagues usually develop during a cycle of years with sub-normal rainfall.

(*d*) There is an obligatory diapause in the egg-stage, with the result that there is only one generation in a year.

(*e*) The length of life and fertility of adults may be reduced by inadequate food during a dry period but there is no evidence of low atmospheric humidity inhibiting development.

The former group includes most of the species that have been recognised as locusts, and the latter includes all the grasshoppers.

The phylogeny of diapause may be traced from the primitive condition in the locusts through an intermediate condition in such grasshoppers as *Melanoplus mexicanus* to the highly specialised condition in grasshoppers of the *Austroicetes cruciata* type.

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NEW HYPOTHESES FOR PREDICTION OF THE SWARMING OF THE DESERT LOCUST.

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The existence in the Desert Locust, *Schistocerca gregaria*, Forskål, of two main types of *solitaria* individuals, *viz.*, 6- and 7-eye-striped (Roonwal, 1936), enables us to study phase-fluctuation in locust populations with greater ease than hitherto. Occasionally 5- and 8-striped individuals also occur in *solitaria* populations, but so rarely that for practical purposes they may be ignored. Rao (1937, p. 41) further showed that locusts from swarms (ph. *gregaria*) always have 6 eye-stripes. He wrote: " The discovery made by Dr. M. L. Roonwal, in January 1936, of the existence of two types of eye-stripes in the Desert Locust has proved to be a very significant character in the study of locust populations. Specimens collected from swarms have invariably been found to be possessed of 6 stripes, while typical extreme ' *solitaria* ' bred in deserts, especially the female ones, have mostly 7 stripes. The forms collected at the time of the great incursion in Mekran of 1935 were found to have mostly 6 stripes, and the same was the case with the pink and yellow forms that migrated into Pasni ' reks ' in May 1932." Confirmation of this is available in Rao & Gupta (1939) and Roonwal (1941, as well as in unpublished data).

First Hypothesis.

From available data (Table I), it is seen that, on the whole, in *solitaria* populations in India during the *solitaria* years 1932-37, 6-striped individuals predominate, the average proportions being 70·4 per cent. 6-striped and 29·6 per cent. 7-striped.

Table I.

Proportion of 6- and 7-eye-striped individuals in *solitaria* years in Mekran. (From Roonwal, 1936, with additions.)

Year	Number		Percentage	
	6-striped	7-striped	6-striped	7-striped
			Per cent.	Per cent.
1932–35	578	149	79·5	20·5
1936...	245	166	59·6	40·4
1937...	221	86	72·0	28·0
Total and average...	1,044	401	70·4	29·6

Occasionally, in small populations and over very small periods (a month or so), 7-striped individuals may predominate (Rao, 1942), but such predominance disappears as soon as larger periods are taken. Volkonsky's (1938) data from N. Africa is not sufficiently extensive and has, therefore, not been taken into account here. Since in a swarm all the individuals are 6-striped, it is expected that in the period immediately preceding the start of swarming the proportion of 6-striped individuals would increase rapidly above the maximum *solitaria* figure (about 80 per cent.) until actual swarming starts when all the individuals would be 6-striped. On this basis the following tentative hypothesis may be put forth:

If in a sufficiently large sample of a *solitaria* population, the proportion of 6-eye-striped individuals rises above about 80 per cent. (maximum figure; average 70·4 per cent.), and tends towards 100 per cent., that population is rapidly on its way towards swarming. Conversely, if in a *gregaria* population the proportion of 6-striped individuals falls below 100 per cent. and tends towards 80 per cent. or lower, that population is on its way towards the acquisition of *solitaria* or non-swarming characters.

In support, Rao's (1942) recent figures for the July 1935 incursion in Mekran may be cited. The proportion of 6- and 7-striped individuals immediately before and after the incursion was as follows:

	6-striped	7-striped
	Per cent.	Per cent.
Before incursion (April–May)	67	33
After incursion (July)...	88	12

Second Hypothesis.

Available data show that in a *solitaria* population the sex-ratios vary with the number of eye-stripes (Table II). In 6-striped individuals the males predominate, and in 7-striped individuals the females predominate.

TABLE II.

Sex-ratios and eye-stripes in *solitaria* years in Mekran.

Eye-stripes	Year	Number of individuals		Percentage	
		♂	♀	♂	♀
6	1932–35	348	230	60	40
	1936	160	85	65	35
	1937	146	75	66	34
	Total and average ...	654	390	64	36
7	1932–35	62	87	42	58
	1936	51	115	31	69
	1937	27	59	31	69
	Total and average ...	140	261	35	65

TABLE III.

Sex-ratios in *gregaria* populations (swarms).

Locality	Number of individuals		Percentage		Remarks	Author
	♂	♀	♂	♀		
Lyallpur (Punjab)	1,769	1,793	49·7	50·3	From swarm of 19 July, 1936.	Husain (1932)
Lyallpur (Punjab)	354	372	48·8	51·2	From swarm of 8 Sept., 1931.	Husain (1932)
Sudan (Africa) ...	313	289	52·0	48·0	Combined from various swarms (1930–34).	Maxwell-Darling (1934).
Total and average	2,436	2,454	52·2	49·8	—	—

In swarms (Table III), when all the individuals are 6-striped (see above), the sexes are almost equal. This suggests that in *gregaria* populations the natural affinity of the 6-striped individuals with the male sex, which is so clearly evident in *solitaria* populations, is partly destroyed, resulting in the partial equalisation of the sexes. On this basis the following tentative hypothesis may be put forward:

If in a sufficiently large sample of *solitaria* population the ♂ : ♀ ratio among the 6-eye-striped individuals tends to vary from about 64 : 36 to 50 : 50, that population is on its way to the acquisition of *gregaria* characters.

Third Hypothesis.

From Table IV it is seen that in *solitaria* populations the percentage of 6-eye-striped individuals (as against 7-striped ones) is, on the average, about 82·4 in ♂♂ and 59·9 in ♀♀ ; in swarms these figures reach 100 per cent. for both sexes, there being no 7-striped individuals.

TABLE IV.

Proportion of 6- and 7-eye-striped individuals in the two sexes during *solitaria* years (1932–37) in Mekran. (From Table II.)

Sex	Total no. of individuals	No. and percentage of 6- and 7-striped individuals	
		6-striped	7-striped
♂♂	794	654 (82·4 per cent.)	140 (17·6 per cent.)
♀♀	651	390 (59·9 per cent.)	261 (40·1 per cent.)

On this basis the following tentative hypothesis may be put forward:

If in a sufficiently large sample of *solitaria* population the proportion of 6-eye-striped individuals rises materially above about 82 per cent. among males and 60 per cent. among females, tending in both sexes towards 100 per cent., that population is on its way towards swarming.

Fuller results will be published elsewhere. I would appeal to field workers to test these hypotheses for the Desert Locust, and also to ascertain whether hypotheses on similar principles can be used for other locusts with eye-stripes, *e.g.*, Italian Locust (*Calliptamus italicus*), Red Locust (*Nomadacris septemfasciata*), etc.

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THE LARVA AND PUPA OF *TAENIORHYNCHUS* (*COQUILLETTIDIA*) *MACULIPENNIS*, THEOBALD.

By J. D. Gillett.

(*By permission of the Director of Medical Services, Uganda.*)

A mixed collection of living *Taeniorhynchus* larvae was obtained by the writer from a shallow grassy swamp at the edge of Lake Victoria (3,720 ft.) at Entebbe, Uganda, in July, 1942. The living larvae were examined in the larvascope (Gillett, 1942), and *Coquillettidia* separated from *Mansonioides*. All fourth-instar larvae of the former subgenus were then isolated in test-tubes of water containing one slender grass stem together with its root. A series of adult *T.* (*C.*) *maculipennis* was successfully bred out, and the respective larval and pupal pelts kept.

The larval and pupal pelts have been examined, together with a number of preserved larvae, and (as might be expected) they show a close resemblance to *T.* (*C.*) *aurites*, Theo., and *T.* (*C.*) *microannulatus*, Theo., the only two African species of the subgenus hitherto described (Hopkins, 1936, and Edwards, 1941). There are, however, in the specimens examined, distinct differences which enable the species to be readily separated from *aurites* and *microannulatus*, the larvae and larval pelts having been compared with larval pelts of the latter two species. A description of the differences found follows.

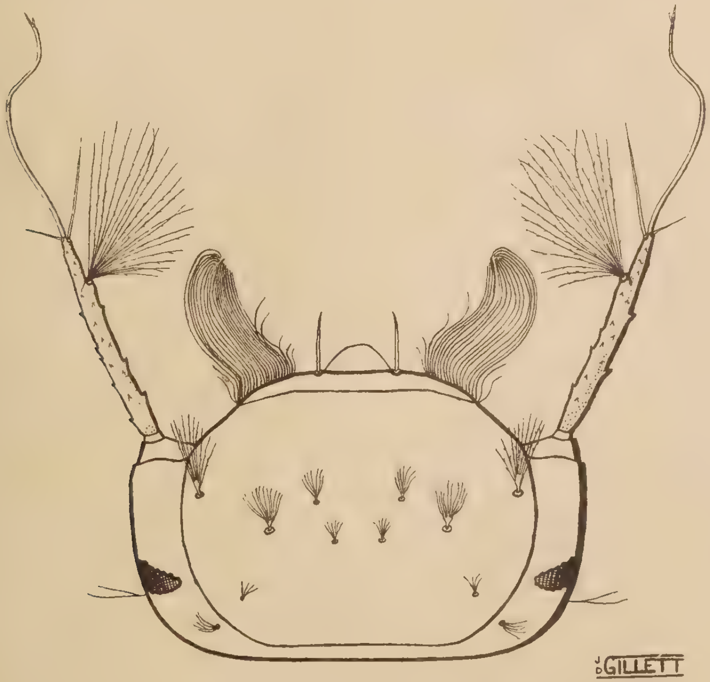

Fig. 1. *Taeniorhynchus maculipennis*, Theo. Head of larva.

Larva.

Head. The longer of the two subterminal setae of the antenna is only half or less than half the length of the flagellar segment of the antenna, and only about three times the length of the shorter subterminal seta. In *aurites* and *microannulatus* it is from two-thirds to three-quarters the length of the flagellar segment, and about four times the length of the shorter subterminal seta. The position of the antennal tuft is the best distinguishing feature, but cannot suitably be expressed in the usual way, *i.e.*, as a fraction indicating the length of the portion of the shaft of the antenna proximal to the tuft divided by the total length of the antenna. It can, however, be expressed as a fraction indicating the length of the portion of the pedicellus proximal to the tuft divided by the total length of the pedicellus only. This gives 4/5 for the present species, and less than 2/3 for *aurites* and *microannulatus*. It should be noted that the actual length of the portion of the pedicellus proximal to the tuft is identical in all three species, but that the portion distal to the tuft in the present species is only half the length of the same portion in *aurites* and *microannulatus*. Hence the real distinguishing feature is the length of the portion of the pedicellus distal to the tuft.

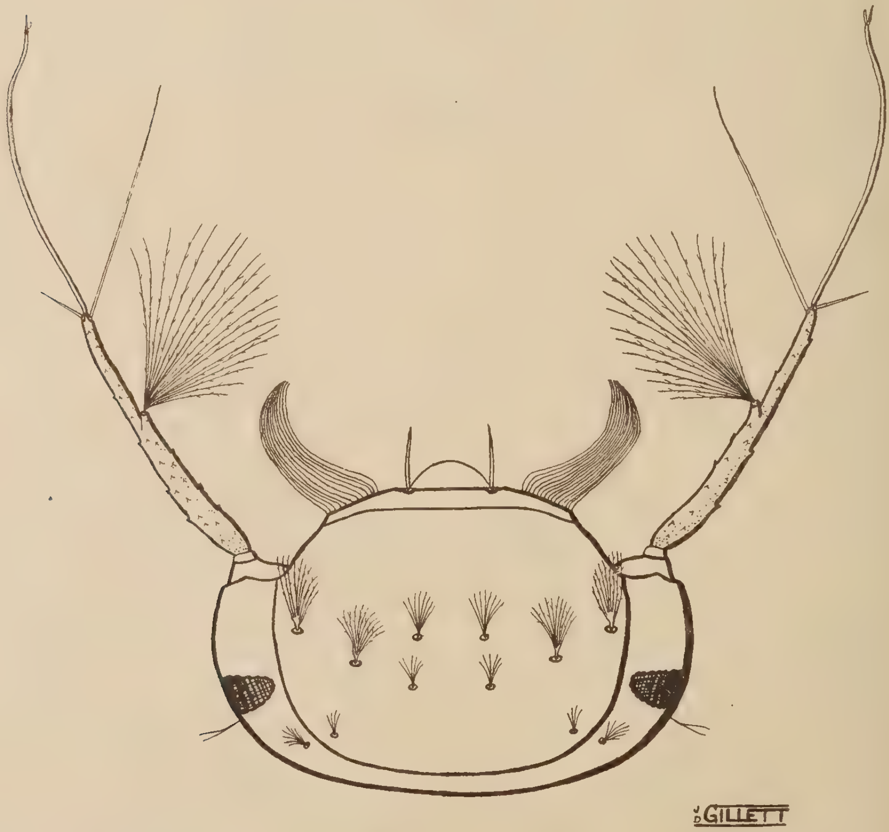

Fig. 2. *Taeniorhynchus aurites*, Theo. Head of larva. Seta B shown plumose as in description (Hopkins, 1936), although simple in material examined by the writer.

PUPA.

Trumpet. Long and mainly cylindrical as in *aurites* and *microannulatus*, but at the distal end of the tracheoid portion of the meatus there is a slight bulbous widening immediately proximal to the narrowed part at the end. Pinna missing in all pelts examined. *Paddle.* Outer point about twice the length of the inner, whereas in *aurites* the outer point is only slightly longer, and in *microannulatus* the two points are about equal in size.

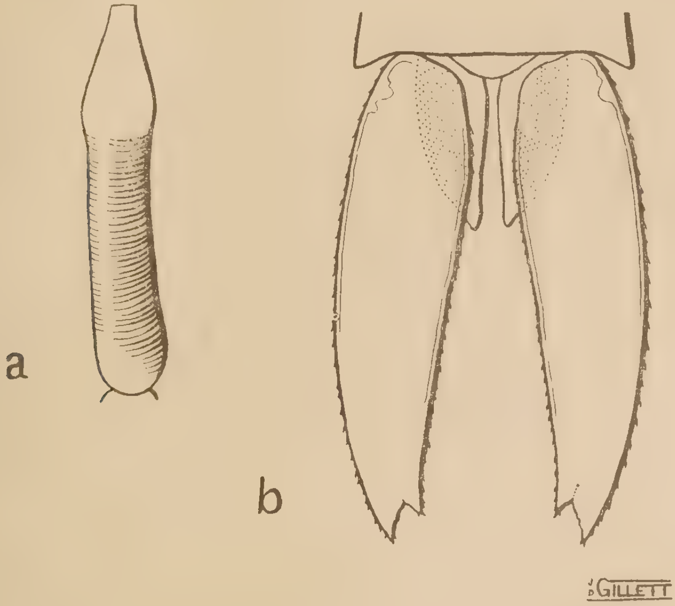

FIG. 3. *Taeniorhynchus maculipennis*, Theo. Pupal details. a, trumpet (pinna missing) b, paddles.

The material is at present in the Uganda Protectorate collection, but it is hoped to present specimens to the British Museum, and to the London School of Hygiene and Tropical Medicine in due course.

Thanks are due to Mr. G. H. E. Hopkins, who kindly provided the pelts of *T. aurites* and *T. microannulatus*.

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LABORATORY STUDIES ON THE BIONOMICS OF THE RAT FLEAS, *XENOPSYLLA BRASILIENSIS*, BAKER, AND *X. CHEOPIS*, ROTHS.

I. CERTAIN EFFECTS OF LIGHT, TEMPERATURE AND HUMIDITY ON THE RATE OF DEVELOPMENT AND ON ADULT LONGEVITY.

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Introduction.

The contribution that laboratory work can make towards the solution of ecological problems depends upon the possibility of exercising greater control over climatic and other factors in the laboratory than in the field, and it should be possible as a result to obtain more precise correlations between any two variables that it is desired to investigate. A considerable amount of laboratory work has been done on the bionomics of fleas, but correspondence in the results of different workers, which might be expected from laboratory work where conditions can be adequately controlled, is lacking in some respects.

Leeson (1932c), for instance, obtained a figure 50 per cent. greater than Hopkins (1935) for the length of life of unfed, adult *Xenopsylla cheopis*, and again, Leeson (1936) found that there is no direct proportion between length of life of unfed fleas and saturation deficiency, whereas Bacot and Martin (1924) had found longevity and saturation deficiency to be directly proportional.

In view of the well-established fact that epidemics of plague occur under conditions which allow rapid breeding of fleas and long periods of survival apart from their hosts (though these conditions are not necessarily the same), the accuracy of longevity figures is important in the prediction and control of outbreaks. The present work was therefore undertaken primarily to find whether there are other important factors concerned in longevity which should be controlled and which might explain differences in results so far obtained.

Material and General Technique.

Material was originally obtained from specimens of *Rattus rattus* caught in the neighbourhood of Kampala, and from some of these a colony was built up, using a technique similar to that described by Leeson (1932a) except that it was found necessary to use baby mice as hosts, because adults ate the fleas and quickly reduced the numbers in the colony.

The conditions of breeding and handling the experimental insects were intentionally varied, and these will be described in detail for the various experiments to which they relate. There are, however, certain features common to all experiments, and these will now be described.

Fleas in all stages of development were kept singly, except where the contrary is stated, in small test tubes, 3 inches high by $\frac{1}{2}$ inch wide, capped with a small piece of voile which was kept in place by a rubber band. The tubes were kept in desiccators and held vertically by wire netting. The saturation deficiency in the desiccators was maintained at the desired level by solutions of potassium hydroxide made up according to the figures given by Buxton (1931). The humidity of the air in the desiccators was measured frequently by a dew-point apparatus, and the solution of potassium hydroxide was renewed once every 14 days. It was found that the relative humidity was always within 2 per cent. of that required and usually within 1 per cent.

It was not possible accurately to control the temperature in the dark room which was used for all the experiments to be described, so that a detailed account of the temperature conditions during the experiments is necessary. Thermograph records, checked by mercury thermometers, were kept during the whole period in which the experiments were carried out, from December, 1941, to June, 1944, and they show only two days during that period when the temperature rose above 80°F. (81° and 82°F. on the 4th and 5th February, 1942) and four days when it fell below 70°F. (69°F. on 26th and 68°F. on 27th-29th August, 1943). The mean daily range, based on the range of every seventh day throughout the period, was 1·56°F. The maximum daily range was 3·8° and the minimum 0·6°F. The mean weekly range, based on weekly records through the whole period, was 3·70°F. with a maximum of 7·0° and a minimum of 2·0°F., and the mean of all values half way between the weekly extremes was 75·17°F., the standard deviation being 1·84°F.

In order to avoid tedious repetition of temperature conditions for each experiment, the figure of 24°C. (75·2°F.) is used to describe the temperature in the dark room.

The variation in temperature described above is unfortunate, but it is felt that the significance of the results obtained is not greatly diminished, since in most experiments two or more series of fleas were kept at the same time for comparison of the effect of other factors, so that all series in any one experiment were subjected to the same fluctuation. Where temperature was a variable, only two temperatures were used, one in the dark room already described, the other in an incubator running at 35°C. where a temperature constant within 0·5°C. could be maintained, and it is submitted that the difference between these two sets of temperature conditions was sufficiently constant to allow of valid conclusions being drawn.

The tubes in the desiccators were examined each day at the same time, as well as any dead fleas to determine sex and species. This meant exposing all tubes to the air for not more than five minutes each day. After the first experiment, more desiccators were available, so that each could contain a smaller number of tubes, and this reduced the daily period of exposure.

In all figures relating to length of time in days, an event which took place between any two daily examinations was considered to have occurred at the time of the second examination. Thus a flea that lived anything from 19-20 days would be considered as having survived for 20 days.

Experimental Results and Discussion.

(a) *Light.*

In all recent work the temperature and humidity conditions of longevity experiments are defined, but reference is seldom made to light. The only work known to the author which is directed especially to finding the effect, if any, of light, is that of Nicoll (1912) on *Ceratophyllus fasciatus.* In this work, however, other conditions were not constant, and as Nicoll remarks, " conditions of light " did " not appear to have any great influence " on the length of life. Hirst (1926) mentions in passing that in one of his experiments fleas were kept in a dark cupboard, but none was kept in the light for comparison.

It seemed advisable, therefore, to commence the search for the unknown factor or factors by finding out whether or not lighting conditions do affect longevity in the adult stage.

EXPERIMENT I.

Fleas for this experiment were obtained from wild *Rattus rattus* trapped in huts and stores. Each rat was lightly chloroformed in order to remove the fleas, and the latter were also anaesthetised in the process. Each flea was put separately into a test tube as described above, and the tubes were numbered. Half the number of fleas from each rat went into the ‘ light ’ desiccator and half into the ‘ dark.’ The two desiccators, with a thermograph between them, were placed in a row across the long axis of a bench in a photographic dark room. The light desiccator was left uncovered, the dark was covered by a large inverted tin, bright on all surfaces, and several layers of black cloth were held in position by a rubber band round the bottom of the tin where it rested on the bench. Light was provided by two 75-watt, Osram pearl bulbs, placed on the bench on opposite sides of the desiccators, each at a distance of six feet from them. The light intensity varied as a result of variations in the mains current, but each lamp considered separately provided an intensity at the desiccators of about 10 foot-candles.

The results of this experiment are shown in Table I. All the standard deviations are large, and this is to be expected since wild-caught fleas will vary considerably in age and state of nutrition, as well as in other respects. All the figures for ‘ light ’ are smaller than the corresponding ‘ dark ’ figures, though the difference is small. Statistical analysis shows that the difference, in the case of *X. brasiliensis* males, between 3·01 days in the light and 3·39 days in the dark, is significant (P > 0·05),* though in the three other comparisons P > 0·1. It seems probable therefore that light of the intensity used does have a small effect, but the variation in length of life due to other causes is so great that a very large number of fleas is necessary to demonstrate the light effect, and the differences found would certainly not account for the discrepancies in previous workers’ results.

TABLE I.

Experiment I. Longevity in days of adult, wild-caught fleas, unfed after capture, kept in the light or the dark, at 24°C. and 4·5 mm. Hg. Sat. def. (80 per cent. R.H.).

		X. brasiliensis		*X. cheopis*	
		Males	Females	Males	Females
Light	No. of fleas	137	67	45	21
	Mean longevity in days ...	3·01	6·22	3·22	6·43
	Standard deviation ...	1·43	2·05	1·20	1·92
	P	*<0·05*	*0·1–0·2*	*0·1–0·2*	*0·6*
Dark	No. of fleas	152	81	37	26
	Mean longevity in days ...	3·39	6·70	3·80	6·86
	Standard deviation ...	1·53	2·52	1·60	1·76

The small effect found in the present experiment might be due to small temperature differences. Leeson and others have shown that unfed adults live longer at lower temperatures than at higher. Many measurements of the air temperature in the two desiccators were made, and these showed that if there was a difference it was less than 0·1°C. Greater accuracy was not possible

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[*] In this and all further references to P, the value was calculated according to Fisher (1941). If P < 0·05 the probability that such a difference would occur by chance is less than 1/20, and the difference is considered as being significant. If P > 0·05 it would be unwise to ascribe any significance to the difference found.

with the apparatus available. But it is well established (Uvarov, 1931) that the internal temperature of dark-coloured insects is frequently higher than that of their surroundings, due to the absorption of radiant heat, and this might have occurred in the above experiment.

The effect of light on *Drosophila* has been investigated by Northrop (1925) who found that at about 2,500 metre-candles the larval period was shortened slightly, as compared with dark-reared flies, but increased at higher intensities. He also found that the imaginal period was shortened at 1,000 metre-candles. It is possible, however, that these are also radiant heat effects.

The figures in Table I also show that females live longer than males in both species. $P < 0{\cdot}01$ in all cases. This has been found by Leeson (*loc. cit.*), Hopkins (*loc. cit.*) and others for unfed wild-caught fleas, and is probably due, as Hirst (1926) suggests, to the smaller size (Webster, 1930) and greater surface-area / volume ratio in males. In newly emerged fleas, which have not fed several times, there is no difference in size between the sexes, and there is then no difference in longevity if they are kept without food. This has been established by Leeson and is confirmed by experiments to be described.

If the two species are compared, P for males in the light is 0·5 and for males in the dark, 0·1-0·2, so that neither difference is significant. In all conditions the *cheopis* figures are a little larger than those for *brasiliensis*, but against this Hopkins found the reverse, so that no difference in longevity between the two species has been demonstrated. In all further experiments *brasiliensis* and *cheopis* were used together. In no experiment was a significant difference between them found, but the numbers of *cheopis* were small, and in case a difference should exist, though undemonstrated in the present work, only the figures for *brasiliensis* are shown in the tables.

EXPERIMENT II.

This experiment was devised to find out whether the longevity observed in experiment I was influenced by the chloroforming of fleas when removing them from the rats. *X. brasiliensis* males and females were removed from rats without anaesthesis and kept in the dark under the same conditions as those in the first experiment. The mean longevity of 33 males was 4·21 days and of 19 females, 9·95 days. These figures, when compared with the corresponding figures in Table I, show a significant difference; $P < 0{\cdot}01$ for each sex.

EXPERIMENT III.

To find out whether lighting conditions affected the longevity of newly emerged, unfed fleas, eggs laid by the fleas used in experiment I were reared. The female was transferred from the tube in which she had laid the eggs. The eggs were divided into three groups, and each group was put into a separate tube. Of the three tubes, two were kept at 24°C. and 4·5 mm. S.D., one in the light and one in the dark, the third tube was kept at 35°C. and 8·2 mm. S.D. (R.H. 80 per cent.), in the dark. The further treatment of this last series and the results derived from it will be more conveniently discussed under experiment IV. Considering now the two series of tubes at 24°C., these were examined daily, and when the eggs hatched, each larva was transferred to a clean tube and a large knife point (about 0·1 gm.) of food was added. The larval food consisted of a mixture made in the following proportions: 5 gm. bran, 100 gm. clean sand and 2 gm. dried ox-blood, and it was baked at 120°C. for three hours before the first use to kill moulds. Daily examination of the tubes was continued, and when a larva formed a cocoon prior to pupation, the cocoon and enclosed larva were transferred to a clean tube. Examination for cocoon formation meant turning the contents of the tube on to a piece of black paper and examining with a hand lens, but it is not thought that this procedure damaged or affected the larva in any way. No larva was out of its tube for more than one minute and usually for a much shorter time.

The pupae were examined daily, and upon emergence of each adult the empty cocoon was removed and the flea remained in the same tube. Hirst (1926) and others have found that emergence is stimulated by vibration. It was considered, however, that the mechanical stimulus attendant upon handling during examination was sufficiently constant for all individuals not to cause more premature emergence or allow more overdue emergence at one time than another, and no further precaution was taken in this respect.

The adults derived from " light " reared pupae were divided into two series, one of which was kept in the light, and the other in the dark. Those derived from " dark " reared pupae were similarly divided. All adults were kept at 24°C. and 4·5 mm. S.D. (R.H. 80 per cent.).

The results are shown in Table II. There was no difference between adult males and females as regards longevity, and since this agrees with the results of Leeson (1932c) and Hopkins (1935), the figures are not shown separately for the sexes. The results do, however, show that adults kept in the light live for a slightly shorter time than those in the dark, and this is true whether the pre-adult stages have been passed in the light or in the dark. The difference in the case of the dark reared fleas is of doubtful significance ($P=0{\cdot}1-0{\cdot}05$) when taken by itself, but when taken in conjunction with the other results already detailed and with the significant difference in light reared fleas, its significance increases. The standard deviation in all four series is large, and to obtain a smaller value for P very many more insects would have to be used. In view of the smallness of the difference found it was not considered worth while to proceed with this line of investigation, but rather to try to find other factors causing larger variations in longevity. In all further experiments, however, insects were kept in the dark.

That other, more important factors do exist is shown by the results of experiment III compared with those of experiment II. In experiment II, the mean longevity in the dark was 4·21 days for males and 9·95 days for females, both unanaesthetised; in experiment III the comparable figure (no significant difference between the sexes) is 28·4 days. Now it is reasonable to assume that a few of the individuals in experiment II must have recently emerged when caught, but the longest-lived female in that experiment lived only 14 days, which is only half the mean figure in experiment III. Moreover, Leeson (1936) showed that the longevity of fleas which had fed several times was greater than those which had fed once, and further, that the latter lived longer than those which had never fed at all. In the present experiments the wild-caught fleas, which had probably fed several times, lived for a very much shorter time than the newly emerged fleas which had never fed at all. It appears, therefore, that the longevity of the adult is affected by some factor or factors in the pre-adult stages, and weight is added to this hypothesis by the fact that Leeson's newly emerged, unfed fleas lived for only 6·5 days under roughly similar conditions to those which allowed a life of 28·4 days in the present experiments.

To return to Table II, it is clear that all pre-adult stages are passed through more quickly in the light than in the dark ($P<0{\cdot}01$ for all stages). It appears probable that this difference, at any rate in the larval and cocoon stages, is due to a temperature effect, produced by the absorption of radiant heat by the contents of the tubes, since it is difficult to see how direct light could reach the larvae or pupae.

The difference between males and females with regard to the length of their cocoon stage is significant ($P<0{\cdot}01$), and this confirms the results of Hopkins (1935)

TABLE II.

Experiments III and IV. The effect of light, dark and temperature upon the duration of pre-adult stages, and upon the longevity of adults derived therefrom.

					Eggs			Larvae			Cocoon stage				Adults			
	Temperature °C.	Sat. def. mm. Hg.	Rel. hum. per cent.	Light or dark	No. of eggs which hatched	Mean duration (days)	Standard deviation	No. of larvae which formed cocoons	Mean duration (days)	Standard deviation	No. of pupae which emerged	Mean duration (days)	Standard deviation		Light or dark	No. of adults	Mean longevity (days)	Standard deviation
	24	4·5	80	L	49	4·3	0·85	48	13·7	1·59	17	males 19·0	0·94	All adults at 24° C. and 4·5 mm. Hg. S.D.	L	23	24·6	5·52
																P	*0·02*	
											30	females 15·0	1·34		D	23	28·0	5·77
P						<*0·01*			<*0·01*		(♂♂)<*0·01*		(♀♀)<*0·01*					
	24	4·5	80	D	63	5·7	0·76	62	15·3	1·60	23	males 21·0	2·32		L	29	24·8	6·37
																P	*0·1–0·05*	
											35	females 17·2	2·38		D	19	28·8	6·31
P						<*0·01*			<*0·01*		(♂♂)<*0·01*		(♀♀)<*0·01*				<*0·01*	
	35	8·2	80	D	40	4·2	0·64	33	11·6	2·36	12	males 17·1	1·84		D	28	21·3	4·51
											16	females 13·7	1·73					

who found the combined larval and pupal period to be greater in males than in females, of Webster (1930) who found females always emerged before males, and of Leeson (1932b).

Hopkins' figures for the duration of the combined larval and pupal periods are much larger than the present ones. He found the mean figure in days for *X. brasiliensis* to be 55·5 (males) and 47·4 (females), while the present figures are 32·7 (males) and 28·7 (females). Hopkins, however, was using a " nominal " temperature of 20°C. and 100 per cent. R.H. Webster's figures agree more closely with the present results; he found the mean larval and pupal periods to be 28 days (females) and 32 (males), though his temperature and humidity conditions were variable and on the whole higher than in the present work. One is again led to suspect that unknown factors are operating during pre-imaginal stages.

(b) *Temperature and Humidity.*

The results of experiments I-III suggest that the longevity of adults might be affected by pre-imaginal conditions, and this is confirmed by experiment IV, described below.

EXPERIMENT IV.

Eggs were obtained from the same fleas as those for experiment III, and were reared concurrently with them. They were subjected to the same treatment as the dark series in experiment III except that they were kept all the time in an incubator at 35°C. and 8·2 mm. S.D. (R.H. 80 per cent.), humidity being controlled as usual by potassium hydroxide solution in a desiccator. The adults that emerged were kept under the same conditions as those in experiment III (24°C. and 4·5 mm. S.D.) except that they were all in the dark. The results are shown in Table II, together with those for experiment III, which have already been discussed.

It is clear from these figures that the duration of each of the pre-imaginal stages is shorter at 35°C. than at 24°C., but more important from the point of view of the present investigations is the fact that the longevity of the adults obtained from pre-adult stages reared at 35°C. is reduced by about a quarter, even though they were kept in the same conditions as those reared at 24°C. The relative humidity in which the pre-imaginal stages were reared was the same for experiments III and IV, but it has been shown by Mellanby (1933 and 1935) and others, that humidity expressed in terms of saturation deficiency is more closely related to insect physiology than relative humidity; and since the saturation deficiency in experiment IV was 8·2 mm. Hg. as compared with 4·5 in experiment III, it cannot be claimed that the difference in adult longevity was produced solely by subjecting the pre-imaginal stages to different temperatures. Mellanby (*loc. cit.*) also shows that the period during which an insect is exposed to a certain saturation deficiency must be taken into consideration. Now the larval and pre-pupal stages of fleas are " water losers," and it seems probable that larvae, subjected to a saturation deficiency of 4·5 mm. Hg. for 15·3 days (experiment III), would be able to retain more water than those in experiment IV, which were subjected to a saturation deficiency of 8·2 mm. although for 11·6 days only, and that therefore, since the pupae are " water savers," the adults in experiment III would emerge with a higher water content than those in experiment IV, and live longer in so far as lack of water is instrumental in causing death.

This, however, is only a tentative hypothesis which depends upon two assumptions, (i) that the mechanism controlling loss of water in flea larvae is very poor or absent and (ii) that the amount of water obtained from food does not vary sufficiently to make up for loss through the spiracles or cuticle in high saturation deficiencies.

TABLE III.

Experiment V. Duration of pre-adult stages at 24° C. and various saturation deficiencies, and longevity of unfed adults derived from them at 24° C. and 4·5 mm. Hg. S.D.

			Eggs			Larvae			Cocoon stage				Adults		
	Relative humidity per cent.	Sat. def. mm. Hg.	No. of eggs which hatched	Mean duration (days)	Standard deviation	No. of larvae which formed cocoons	Mean duration (days)	Standard deviation	No. of pupae which emerged	Mean duration (days)	Standard deviation		No. of adults	Mean longevity (days)	Standard deviation
	90	2·3	50	5·2	0·59	22	12·4	1·86	10	males 19·0	1·27	All adults at 24° C. and 4·5 mm. Hg. S.D.	21	20·3	4·31
									11	females 14·4	2·14				
P							< *0·01*							<*0·0 1*	
	80	4·5	43	6·0	0·57	31	16·7	2·50	14	males 19·6	3·11		29	25·5	4·63
									16	females 15·1	1·52				
P							< *0·01*							*0·6*	

	70	6·7	67	5·1	0·76	50	24·0	4·47	25 23	males 20·0 females 16·4	2·65 2·85	All adults at 24° C. and 4.5 mm. Hg. S.D.	47	25·2	5·10
P							< *0·01*							< *0·01*	
	60	8·8	51	4·7	0·60	30	25·1	4·31	14 16	males 19·3 females 17·3	1·86 2·05		30	18·4	4·12

As regards assumption (i), Mellanby (1934) found that although 5 per cent. CO_2 in air was sufficient to keep the spiracles of adult *Xenopsylla* wide open and to double the loss of water, the same concentration of CO_2 had no effect upon the water loss of larvae, and he therefore assumed that there was no spiracular mechanism in larvae. Sharif (1937) however, described a spiracular closing mechanism in *Nosopsyllus* (*Ceratophyllus*). Buxton (1938) suggests that the larval cuticle is permeable to water and the spiracular mechanism inefficient.

Assumption (ii) rests upon the evidence of Wigglesworth (1932), who showed that the extraction of fluid from the hind gut is much less efficient in larvae than in adults, and that of Sikes (1931), who showed that different substances on which larvae might feed are differentially hygroscopic, and that larvae are very dependant upon the amount of water present in the food. On the other hand Buxton (1930) found that meal-worm larvae obtain water from dry food by metabolism.

EXPERIMENT V.

This experiment was devised to find out whether different saturation deficiencies in the pre-imaginal stages would alone affect the longevity of adults. Eggs were obtained from fleas in the breeding jars. All the adult fleas were removed from the jar in the evening and transferred to a clean vessel lined with black cloth and covered with voile. On the following morning they were replaced in the breeding jar, and the eggs which had been laid during the night could easily be found on the black cloth. In order to obtain sufficient eggs, the procedure was repeated four times at intervals of four days. The eggs were kept in the vessel in which they had been laid, and the vessel was kept at 24°C. and at the required humidity in a desiccator. The first batch of eggs laid was kept at 2·3 mm. S.D. (90 per cent. R.H.), the others at 4·5 mm. S.D. (80 per cent. R.H.), 6·7 mm. S.D. (70 per cent. R.H.) or 8·8 mm. S.D. (60 per cent. R.H.). When the eggs hatched each larva was transferred to a separate tube and kept at the same temperature and saturation deficiency as the egg from which it had hatched. Further treatment was the same as in experiment III, and upon emerging, each adult was put into a clean tube and kept at 24°C. and 4·5 mm. S.D. (80 per cent. R.H.), no matter under what conditions it had been reared. The results are shown in Table III.

The egg period appears to increase as the S.D. decreases from 8·8 to 4·5 mm. Hg., but to decrease when the S.D. is less than this. The value of these figures is doubtful, however, since the interval between observations, 24 hours, is very large compared with the whole period. Other methods would have to be adopted if it were desired accurately to find the effect of humidity on the duration of the egg period. Attempts were made to rear eggs at higher saturation deficiencies, but none hatched at a S.D. of 10 mm. or more.

The effect of humidity on the duration of the larval stage is striking. This increases from 12·4 to 25·1 days as the S.D. increases from 2·3 to 8·8 mm., and the differences between the periods are all significant, though the last difference is smaller than the other two. As regards the cocoon period, saturation deficiency appears to have no effect, though again the difference between males and females is significant at all humidities used. Buxton (1938) found that the whole pre-adult period is shorter at higher humidities, and the present results show that this difference occurs largely in the larval stage.

The adults from all these insects show an interesting variation in longevity. This is significantly shorter if the pre-imaginal stages developed at either 2·3 mm. or 8·8 mm. S.D. than if they developed at either of the intermediate humidities. It is possible that the reason for this variation is as follows:—At a S.D. of 8·8 mm. the larval period was slightly longer than at 6·7 mm., so that at the end of larval development the former larvae would have a lower water content than the latter, and would therefore have less water at the beginning of their period of starvation as adults. Buxton (1938) combined his own results with those of Bacot (1914) in the form of a graph showing saturation deficiencies at various temperatures which were either favourable or unfavourable to the production of adult *Xenopsylla* from larvae. According to this graph, 24°C. and 8·8 mm. S.D. is just on the unfavourable side of the borderline, and this is borne out by the fact that of 51 larvae under those conditions in the present experiment only 30 pupated.

At a S.D. of 6·7 mm., conditions according to Buxton's graph are just on the favourable side, while a deficit of 4·5 mm. is well in the favourable area. Now the larval duration found in the present work was 24·0 days at 6·7 mm. S.D. and 16·7 days at 4·5 mm. S.D., but there was no difference in the longevity of adults derived from these larvae. It seems, therefore, that the larvae in the lower humidity were able, during their longer life in just favourable conditions, to accumulate the necessary amount of water, and possibly grow to the necessary size, so as to enable them to live, as adults, as long as those which, as larvae, had been in the higher humidity.

Considering now the larvae in 2·3 mm. S.D., their duration was shorter still, 12·4 days, and their short longevity as adults is difficult to account for. One possible explanation is that the psychrometric conditions being favourable to rapid development, they pupated before having grown to the same size as those at greater saturation deficiencies, and therefore emerged as smaller adults, not capable of resisting starvation and desiccation for so long. (It is hoped to settle this point at a later date by finding the weight and water content of larvae under different conditions.) On the other hand, it appears from the proportion of larvae that survived (44 per cent.) that the conditions, though conducive to rapid development, were not otherwise favourable. No mould was actually noticed, but the possibility of fungal or bacterial infection cannot be excluded, and if such did occur it might well be responsible for shortening the mean adult longevity.

EXPERIMENT VI.

This experiment was designed to find out whether differences in saturation deficiency during the cocoon stage only would have an effect upon the longevity of adults. Cocoons, with pre-pupae not more than 24 hours old, were obtained by examining the material in the breeding jars daily. All cocoons were removed on the first two examinations, and those obtained at the third and subsequent examinations were used for the experiment. The breeding jars had been kept previously in a dark cupboard, and the relative humidity inside the jar was about 86 per cent., though it varied between 82 and 89 per cent. The precise humidity at which the eggs and larvae had developed was not determined, but it must have been high since a baby mouse was present in the jar all the time. The temperature in the cupboard was measured every morning during the period in which the eggs and larvae were developing. The highest recorded was 23·5°C., the lowest, 22·0°C. It can be said then, that although the temperature and humidity conditions of the eggs and larvae fluctuated, the fluctuation was not great, and all were subject to similar fluctuations.

Each cocoon was placed in a separate tube, and the tubes were kept at 24°C. and at the same variety of saturation deficiencies as in experiment V. All adults upon emerging were kept at 24°C. and 4·5 mm. S.D. (R.H. 80 per cent.). The results are shown in Table IV.

TABLE IV.

Experiment VI. The duration of the cocoon stage at 24°C. and at various saturation deficiencies, and the longevity of adults derived from them, at 24°C. and 4·5 mm. Hg. S.D.

				Cocoon stage			Adults			
	Series	Saturation deficiency (mm. Hg.)	Relative humidity per cent.	No. of pupae which emerged	Mean duration (days)	Standard deviation		No. of adults	Mean longevity (days)	Standard deviation
	A	2·3	90	29	males 17·6	2·79	All adults at 24°C. and 4·5 mm. Hg. S.D.	70	20·1	4·91
				42	females 14·0	2·06				
P				(♂♂) *0·5*		(♀♀) *0·5*			*0·1—0·2*	
	B	4·5	80	53	males 17·5	2·95		109	19·0	5·06
				56	females 13·4	2·48				
P				(♂♂) *0·1*		(♀♀) *0·5*			< *0·01*	
	C	6·7	70	38	males 16·5	2·81		82	17·8	4·52
				47	females 13·0	1·98				
P				(♂♂) < *0·01*		(♀♀) < *0·01*			< *0·01*	
	D	8·8	60	25	males 19·5	2·15		66	16·8	4·17
				41	females 15·3	2·78				

The duration of the cocoon stage is not, apparently, affected by humidity except at 8·8 mm. S.D., where the duration is significantly longer in both sexes than at 6·7 mm. or less. In all humidities the male cocoon stage was again significantly longer than the female. Adult longevity shows a steady fall from 20·1 to 16·8 days as the saturation deficiency in which the pupae were kept rises from 2·3 to 8·8 mm. Hg. and the differences are significant except the one between series A and B where P=0·1–0·2.

Now it has been shown by Mellanby (1933) that when true pupation has occurred, absolutely dry air does not prevent emergence, so that the pupa is a true water-saver. The pre-pupa, however, is a water-loser, as shown by the fact that pupation will only take place if the saturation deficiency is below a certain maximum which varies with the temperature. It follows that the cause of the difference in longevity of the resultant adults in the present experiment is the different amounts of water lost in the pre-pupal stage.

Further, the time taken to pupate after cocoon formation is stated by Mellanby to be constant at any one temperature even though the saturation deficiency may vary. If this is accepted, despite the small difference in total cocoon period found between series C and D in the present experiment (which might be due to the effect of humidity on emergence, not on pupation), and if it is further assumed that the rate of loss of water from a pre-pupa is proportional to the saturation deficiency, then a graph of adult longevity against saturation deficiency during the pre-pupal stage should be a straight line.

This graph has been drawn (fig. 1), and it will be seen that the points do lie very close to a straight line. If the line be extended towards the ordinate, it cuts the latter at a point representing 21·3 days, and this is the theoretical longevity of adults whose pre-pupal stage was passed in saturated air. The difference between this figure and the various longevities found should be proportional to saturation deficiency, in other words, Difference/Saturation deficiency = K. In Table V the values for K have been calculated, and K is seen to vary only slightly.

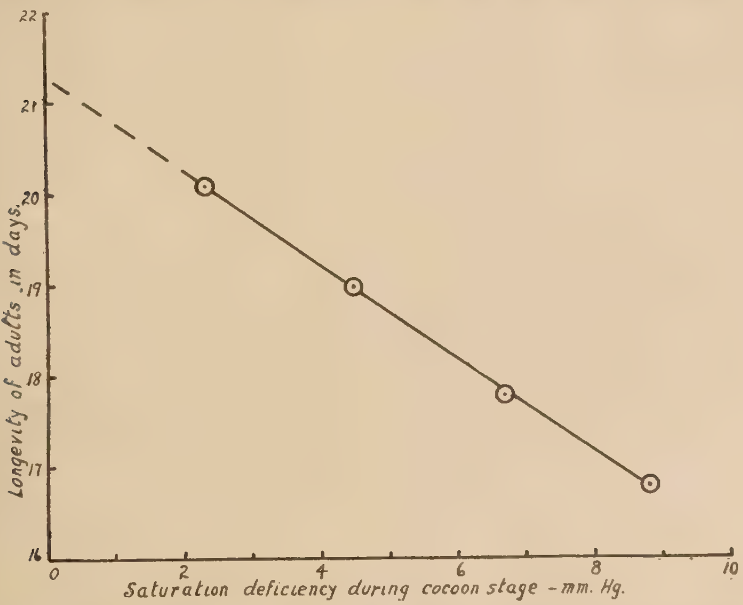

FIG. 1. The relation between adult longevity and saturation deficiency during the cocoon stage.

TABLE V.
Experiment VI.

A Amount by which adult longevity falls short of theoretical maximum	B Saturation deficiency during pre-pupal stage	C K (=A/B) × 10
1·2 days	2·3 mm. Hg.	5·217
2·3 days	4·5 mm. Hg.	5·111
3·5 days	6·7 mm. Hg.	5·224
4·5 days	8·8 mm. Hg.	5·114

The fact that no significant difference in longevity was found in this experiment between males and females appeared strange, since the male cocoon stage lasted longer than the female in each humidity, and was therefore exposed to any given saturation deficiency for a longer time.

A determination was therefore made of the length of the pre-pupal period, by opening cocoons 3, 4, 5 or 6 days after formation. Once a cocoon was opened it was discarded if pupation had not taken place. If the pupa had been formed, it was kept and the sex of the adult determined later. All cocoons were kept at 24°C. and 4·5 mm. S.D. Of 75 cocoons containing pupae when examined, 19 per cent. were observed after three days, 54 per cent. after four days, 23 per cent. after five days and 4 per cent. after more than 5 days. The mean number of days in which pupae had been formed was 4·14, so that the pre-pupal period is probably nearly four days in the conditions stated. No difference was found between males and females. The reason for the apparent anomaly may therefore be that the two sexes have equally long pre-pupal periods, and even if not, the difference would be very small.

Bacot & Martin (1924) claimed to have found adult longevity to be proportional to saturation deficiency. Leeson (1932c and 1936) on the other hand, found that " there is no direct proportion between length of life of unfed fleas and saturation deficiency ". He also states that he found " no relationship " between length of life and saturation deficiency at any temperature, whether the fleas are fed once or several times. Bacot & Martin and Leeson all appear to use " no direct proportion " and " no relationship " synonymously. It is not to be expected that longevity of unfed fleas should be in proportion to saturation deficiency, since the cause of death is not only loss of water but starvation as well, as was pointed out by Mellanby (1935). That author, commenting on the apparent conflict between Leeson's work and that of Bacot and Martin, suggests that since Leeson's fleas came direct from pupae they died of starvation, while Bacot and Martin's came from rodents and therefore died of desiccation. The present results show that the longevity of adults derived direct from pupae is *partly* affected by water content. There is no direct proportion between adult longevity and saturation deficiency during the pre-pupal period in the present results, but there is a relationship, and it can be expressed by the formula $\frac{M - I}{d} = K$, where M = theoretical maximum longevity, I = actual longevity of adults and d = saturation deficiency during the pre-pupal stage. It must be emphasised, however, that this relationship has been shown to hold only when the pre-pupae are subjected to different saturation deficiencies; the mechanism for control of loss of water in adults may upset the relation if the adults are kept in different humidities.

The figures for the duration of pre-adult stages found in experiment IV should now be re-examined in the light of experiments V and VI. In experiment IV (Table II), the duration of all pre-adult stages is seen to be shorter at 35°C. than at 24°C. if the relative humidity is the same. It was pointed out, however, when these figures were being discussed (p. 405), that the saturation deficiency was not the same at both temperatures, so that the shorter pre-adult periods were not then ascribable to increased temperature, but might have been due to increased saturation deficiency. But in experiments V and VI an increase in saturation deficiency is found to increase the larval period and have no effect upon the cocoon period. It follows, therefore, that the decrease in larval and pupal periods found in experiment IV cannot be ascribed to increased saturation deficiency, and must be the result of a higher temperature.

EXPERIMENT VII.

In this experiment, material (mouse bedding) obtained from the bottom of breeding jars, containing eggs, larvae and pupae, was put in an incubator running at 35°C. where the saturation deficiency was about 4·0 mm. Hg. (90 per cent.

R.H.). On the seventh day after placing the bedding in the incubator the saturation deficiency was allowed to increase by removing the basin of water which had been previously kept there. The saturation deficiency then rose irregularly from 4·0 to 18·0 mm. over a period of 9 days and then remained fairly constant.

TABLE VI.

Experiment VII.

No. of days in incubator before emergence.	2	4	6	8	10	12	14	16	18	20
Mean longevity of 10 adults at 24° C. and 4·5 mm. Hg. S.D.	11·8	12·8	12·4	11·6	12·8	11·5	12·9	14·2	14·4	13·5

No. of days in incubator before emergence.	22	24	26	28	30	32	34	36	38	40
Mean longevity of 10 adults at 24° C. and 4·5 mm. Hg. S.D.	12·0	8·9	9·6	7·7	5·0	6·3	6·0	4·1	5·0	4·9

Adults were emerging from the bedding during the period of incubation and ten were taken every two days, commencing on the second day of incubation, to determine their longevity at 24°C. and 4·5 mm. S.D. The results are shown in Table VI, from which a graph (fig. 2) has been drawn. In the graph, the mean longevity of each batch of ten is plotted against the number of days which the bedding (and therefore the pupae from which the adults emerged) had been in the incubator. The point A on the graph indicates the day on which the saturation deficiency began to fall, B indicates roughly the day on which the longevity of the adults begins distinctly to shorten. The distance between A and B is seen to represent 16 days, and reference to Table II shows that the cocoon stage at 35°C. takes about 14 days for females and 17 days for males. So that the first adults whose longevity was briefer than " normal " were those whose pre-pupal and pupal stages had been passed in drier air than " normal ". Furthermore, the decrease in adult longevity continues from the 23rd to the 30th day and then remains fairly constant, a period of seven days which is comparable (allowing for the approximation inherent in the technique) with the period of nine days during which the humidity was decreasing in the incubator.

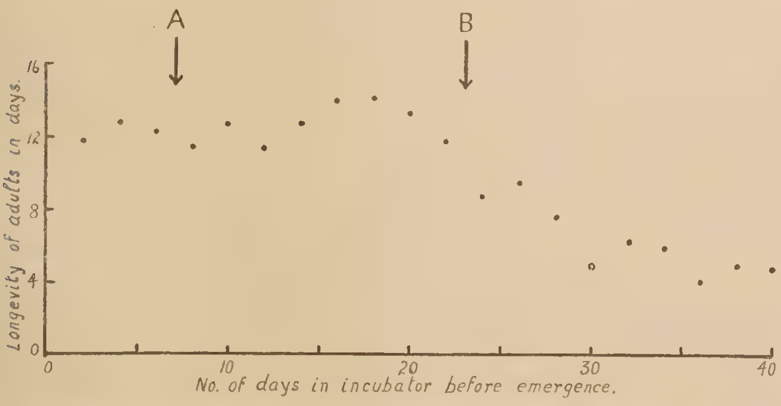

FIG. 2. The effect upon adult longevity of saturation deficiency during the pre-pupal stage.

It would be incautious to draw any further conclusions from these rather inexact figures, but the results do corroborate those of previous experiments in pointing to humidity during the pre-pupal stage as being important in determining the longevity of unfed adults.

General Discussion.

The results of separate experiments have already been discussed, and it remains only to consider what general conclusions can be drawn. The main purpose of the investigation was to look for factors which had not been controlled in previous work and which might explain differences in results hitherto obtained. In particular the results of Leeson conflict with those of Hopkins as regards mean longevity figures, and with those of Bacot and Martin as regards the relation between saturation deficiency and adult longevity. This latter point has already been discussed (see p. 412), and the results of the present work must now be compared with those of Hopkins and Leeson.

Most of Leeson's results were obtained with *Xenopsylla cheopis,* while Hopkins used chiefly *X. cheopis* and *X. brasiliensis,* and his results show no significant difference between the behaviour of the two species. In the present work *brasiliensis* and *cheopis* were both used, but in no experiment was a significant difference found. It is therefore submitted that the results found for *brasiliensis* in the present experiments are comparable with those found for *cheopis* by Leeson.

Hopkins found the longevity of wild caught *brasiliensis* to be 4·6 days (males) and 8·1 days (females) at 15°C. and 60 per cent. R.H. (S.D. 5·1 mm. Hg.), which, allowing for different psychrometric conditions, agrees fairly well with the present figures of 3·39 and 6·70 days in the dark. Hopkins (personal communication) has informed the author that all his fleas were kept in the dark, and that the wild-caught insects were lightly anaesthetised with the rat from which they were taken. Leeson did not use any wild-caught fleas.

Dealing with newly emerged fleas, bred in the laboratory, Hopkins found that at 20°C. and in nearly saturated air the mean longevity of *brasiliensis* was 21·0 days (males) and 21·1 days (females) with no significant difference between the sexes, or between the two species. He found, however, very large standard deviations from the means, 8·95 and 9·59 respectively, for the two figures quoted. His fleas had been bred under various conditions of temperature and humidity, and as the present work has shown, this would affect the longevity of the adults and explain the very large standard deviations found.

Leeson, using laboratory bred fleas, found that newly emerged adult *cheopis* lived for 14·6 days at 18°C. and 1·6 mm. S.D., or 6·5 days at 23°C. and 1·1 mm. S.D. If Hopkins' conditions are assumed to be intermediate between the two sets cited from Leeson's work (as regards temperature this is so, and Leeson himself has shown that small differences in humidity have but little effect) then Leeson would have obtained a figure of about 10·5 days where Hopkins obtained 21 days. To what extent can this difference be ascribed to different psychrometric conditions during the pre-imaginal stages? The greatest saturation deficiency to which these stages were exposed by Hopkins was 5·2 mm., and in most experiments the air was saturated. Leeson (1932a) states that the jars in which *Xenopsylla* spp. were bred, were kept at 23°C. in a " moist incubator ", and since a mouse was present in the breeding jar, the saturation deficiency must have been low, and would therefore not account for the shorter adult life.

In the present experiments, laboratory bred adults kept under similar conditions to those cited from Hopkins and Leeson lived for about 25 days in the light and 28 days in the dark (see Table II), thus agreeing more closely with Hopkins' results. But in experiment VII, the first adults to emerge, which developed in the breeding jar at 23°C. and about 90 per cent. R.H. (S.D. 1·5 mm.), lived only about 12 days. Furthermore, newly emerged adults taken from the breeding jar at other times, for purposes other than the experiments at present described, but kept at 24°C. and 4·5 mm. S.D., were found to live only about 11 days.

It appears, therefore, that these differences are not entirely accounted for by the factors found to operate in the present experiments, and the problem remains unsolved. It is worth noting, however, that Hopkins' fleas and those in the present experiment II mentioned above, which lived for over 20 days, were bred in single tubes, apart from mice; whereas Leeson's fleas, and those in the present experiment VI, which lived for 12 days or less, were all bred in mouse bedding in breeding jars.

There are indications from work at present in hand that other factors operating during the larval stage, and possibly associated with the content of larval food, are responsible for the large differences in adult longevity observed, and it is hoped to be able to define these factors on a subsequent occasion.

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Summary.

1. The effect of light on adult longevity and on the duration of pre-adult stages, and the effect of psychrometric conditions during pre-adult stages upon adult longevity were investigated in *Xenopsylla brasiliensis* and *X. cheopis*.

2. In no experiment was a significant difference found between the two species, but the figures shown are those for *brasiliensis* only, as the numbers of *cheopis* were small.

3. Light reduces slightly the longevity of unfed, wild-caught adults, and of unfed laboratory bred adults; it reduces considerably the duration of all pre-adult stages. It is suggested that this is due to radiant heat.

4. If fleas are anaesthetised while being removed from their hosts, the mean longevity is significantly reduced.

5. It was confirmed that wild-caught females live longer than males, that the cocoon stage of females is shorter than that of males under all conditions used, and that newly emerged, unfed adults show no difference in longevity between the sexes.

6. Eggs fail to develop at 24°C. if the saturation deficiency is 10 mm. Hg. or more; below this, saturation deficiency has little or no effect upon the duration of the egg stage.

7. At 80 per cent. relative humidity, all the pre-adult stages are shorter at 35°C. than at 24°C. If all the adults are kept in the same conditions, those resulting from pre-adults kept at the higher temperature live for a shorter period than those resulting from pre-adults kept at the lower temperature.

8. At 24°C. the larval period increases from 12·4 to 25·1 days as the saturation deficiency increases from 2·3 to 8·8 mm. Hg., but this range of saturation deficiency has no effect upon the duration of the cocoon stage.

9. Saturation deficiency during the pre-pupal stage is shown to bear a linear relationship to adult longevity.

10. The results obtained by previous workers are discussed in the light of the present work, and a possible explanation is suggested for certain discrepancies that still exist.

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ERRATA

Page 73, 8 lines from end, for " Muls." read " F."
,, 112, line 9, for " flies " read " files "
,, 205, line 31, for " *scelestis* " read " *scelestes* "
,, 283, line 16, and page 295, line 2, for " Clausey " read " Causey "
,, 377, line 20, for " Anthribid." read " Dermestid."

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